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Review of Risk Assessment Tools to Predict Morbidity and Mortality in Elderly Surgical Patients

Brief title: Review of surgical risk assessment tools

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ABSTRACT

Background

Informed surgical consent requires accurate estimation of risks and benefits. Multiple risk assessment tools are available; however, most are not widely used or are specific to certain interventions. Assessing surgical risk is especially challenging in elderly patients because of their range of comorbidities, level of frailty, or severity of illness and a number of available surgical interventions.

Data sources

We searched MEDLINE from January 2014 to July 2017 for studies that used risk assessment tools in studies on elderly surgical patients. We then sought the original articles describing each assessment tool and subsequent validation studies.

Conclusions

We identified risk assessment tools that can improve surgical risk assessment in elderly surgical patients. The majority of the identified tools are not commonly used for pre-operative risk assessment. NSQIP-PMP, mFI and SURPAS are promising tools. Age is commonly used to predict risk, but frailty may be a more appropriate measure.

Introduction

Informed consent is critical before surgical interventions are performed. Determining the risks of a surgical procedure that are specific to each patient is important to identify if the benefits outweighs the risks. However, surgical prognostication is challenging due to the differences between development and validation populations compared to the populations in which the tools are applied in clinical practice[1]. Unfortunately, without risk stratification tools, a clinician can only provide their subjective experience-based assessment for surgical outcome.

Risk assessment or clinical prediction tools have been developed and validated to guide decision-making and allow comparison of surgical outcomes[2]. These tools are typically derived using retrospective data on pre- and intra-operative factors routinely collected in large administrative databases to stratify patients according to risk of adverse events[2]. An ideal clinical prediction tools in elderly surgical patients, would include all known elder-specific risk factors and demonstrate improved outcomes in the elderly, it would allow better comparison of estimated future quality of life and prognosis with or without surgical intervention[2]. It would also allow patient centred discussion and decisions, and more equitable distribution of healthcare resources than consideration of age alone. However, the sheer number of available tools makes it difficult to choose which risk assessment tool to use. Different tools are designed or validated to predict different outcomes and have been developed in different surgical populations.

A previous study compared the reliability of risk assessment tools in elderly emergency surgical patients to that of surgical expert opinion[2]. To date no study has compared the uses, advantages, and limitations between these tools. Thus, the purpose of our review is to summarize recent literature on the most common and emerging methods of risk-assessment in surgery to allow health care providers to choose the most relevant predictive tools for their older patients.

Materials and methods

We searched MEDLINE from January 1, 2014 to July 20, 2017 for elderly or aged AND surgery AND grading system or risk or risk assessment AND post-operative complications or mortality. We sought to identify commonly used risk assessment tools in recently published scientific literature. We limited our search to studies with human subjects published in English. We identified 4990 titles. Two authors (GE and MA) screened each article to identify which risk assessment tools were used in each study. All risk-assessment tools that were used 2 or more times in the reviewed abstracts were considered for inclusion, no matter the year the tool was originally published. We then sought the original scientific article describing each identified risk assessment tool. Data extraction was performed with data collection tools that were created for this review before extraction to ensure uniform data collection. If we were also able to identify literature that allowed the tool to be applied to patients who are 65 and older the assessment tool was included in this review. Common univariate predictors were also identified in a similar manner. We excluded tools specific to a single surgical intervention, geographic region, or if it included post-operative factors. We have also not discussed tools that cannot be easily administered within an emergency department or that were not adequately described to permit clinical use. We sought information on clinical or demographic variables, clinical outcomes, limitations, and any assessment of predictive ability (e.g. c-statistic or receiver operating curve).

Results

Single variable predictors of risk

Many univariate predictors of morbidity and mortality were identified. The five of the most commonly identified predictors of risk were: age, completion of a do not resuscitate order, surgical urgency, sarcopenia and frailty. Other univariate predictors or risk include body mass index, pre-operative anemia, alcohol abuse, pre-operative activities of daily living and diabetes. Many of these predictors are included in the multivariate risk assessment tools discussed later.

Age is a readily available predictor of mortality and is used in 9 multi-variable studies discussed below[3–12]. One-year mortality among all people aged 90 years is 19% for men and 15% for women; following elective abdominal surgery it rises to 27.8%[13]. Increasing mortality reflects, to some degree, increasing frailty associated with senescence[14]. Increasing age is also known to nearly double failure-to-rescue rates from complications[15]. However, the relationship between mortality and age varies with presenting condition and, more importantly, with the physiologic reserve, or frailty, of the individual compared to his or her age group[2,14,16]. Studies have found that frailty predicts operative outcomes better than age[17–19].

Completion of a Do Not Resuscitate (DNR) order is a predictor that has been used in multivariable predictors such as National Surgical Quality Improvement Program (NSQIP) Pre-operative Mortality Predictor (PMP)[9]. A matched study of the NSQIP database found increased length of stay (36% increase, $p<0.001$), morbidity (31.0% vs. 26.4%, $p<0.001$) and mortality (23.1% vs. 8.4%, $p<0.001$) among those whom had a DNR order[20]. DNR orders are also associated with increased mortality in cardiothoracic surgery (OR 4.78, $p<0.001$) [21], elderly emergency general surgery (OR 2.07, $p<0.001$) [22] and for intestinal obstruction surgery in the elderly (OR 1.54, $p=0.04$) [22,23]. While there is a significant difference in 30-day mortality between those with a DNR order and those without, the use of a DNR order as a predictive tool in isolation is not advised, since there is varying correlation between presenting condition and the fitness of the individual [23]. Most studies also identified significantly higher comorbidities and acuity of presentation among those with DNRs [21,22].

Emergent procedures have been shown to result in higher morbidity (81.9% vs. 61.6%, p=0.007) and 1-year mortality (49.1% vs. 27.8%, p=0.02), longer length of stay (12 days vs. 8 days, p<0.001) and increased ICU admission (44.4% vs. 11.0%, p<0.001) in those 90 and older [13]. They have also been shown to have similar effects in a colorectal subset of patients and in the general NSQIP dataset for all emergent general surgery procedures [24,25]. Analysis of NSQIP data found emergency surgery patients are more frequently underweight, have higher dependence, are receiving dialysis, have ascites and sepsis[24]. Mortality was 5.8% in the emergency population and 0.8% in the elective population[24]. Emergency versus elective surgery has been incorporated into many predictive tools discussed below including APACHE II[4], PAFS[7], POSSUM[10] and p-POSSUM[11].

Sarcopenia is defined as loss of muscle mass and function, multiple techniques that incorporate radiographic and physical assessment have been developed and are discussed at length elsewhere[26]. Two standard radiographic methods to assess muscle volume and their association with outcomes include total skeletal muscles divided by total body area (cm^2/m^2) on computed tomography scan at L3 [27] and low lean psoas muscle cross-sectional area at L4 [28]. Sarcopenia has been shown to significantly correlate to morbidity and mortality in emergency and elective general surgery (morbidity 45% vs. 15%, p=0.005; mortality 23% vs. 4%, p=0.04) [28,29], colorectal surgery (mortality 8.8% vs. 0.7%, p=0.001) [30], pancreatic surgery (mortality Hazard ratio [HR] 1.68, p<0.001) [31], endometrial cancer surgery (recurrence-free survival HR 3.99, 95% confidence interval 1.42-11.3) [32], and liver transplantation (mortality HR 3.7, p>0.001) [33,34]. The threshold for defining sarcopenia remains under debate [27].

Frailty is defined as both a syndrome and state that confers exaggerated vulnerability[35]. As a syndrome, frailty can be a physical phenotype, not unlike sarcopenia, or it can be multidimensional, with expression as geriatric syndromes. Frailty as a surgical risk prediction tool tends to be implemented as a multivariate prediction tool; it is discussed further below.

Other univariate risk assessment tools identified that we have not discussed in detail include Body Mass Index, substance abuse, anemia or transfusion, diabetes, activities of daily living and fitness testing. While correlated with frailty, functional assessments such as Timed-up-and-go test and grip strength were created with the intention of being functional assessments. We have chosen to focus on broader tools designed to assess mortality risk and opted not to include functional assessments in the manuscript.

Multivariate predictors of risk

The American Society of Anesthesiologists (ASA) physical status classification[36] allows for assessment of perioperative risk. ASA comprises 6 classes of increasing risk ranging from healthy to brain-dead. It has been extensively validated; mortality in ASA 1E is 0-6% whereas 5E is 75-100%[2]. The ASA score has also been incorporated into multi-variable predictors (Table 1). It is frequently incorporated into surgical research to categorize patients by risk profile [2,23]. ASA is limited by moderate inter-rater reliability [37] and no clear definition of which comorbidities should be captured in each ASA physical status category [38]. The score has also been criticized for not specifically including patient demographics.

The Charlson comorbidity index (CACI) predicts ten-year mortality based on a weighted score of 22 conditions along with age [5]. It incorporates medical, infection, and oncologic history including end-organ dysfunction and was developed in patients admitted to a medical ward and has been validated in surgical populations at 30-days [39,40] and 5 years[6]. The relative risk of one-year mortality in a post-operative population is 1.42 per decade of life past 40 and 1.46 per “comorbidity rank”[6]. More recently, 30-day mortality has been found to be associated with increasing CACI; the ROC curve has a c statistic of 0.90 [39] in emergency general surgery patients. The scores used to calculate the CACI are presented in Table 2.

APACHE II is a modification of APACHE I [4]. It was designed to predict ICU mortality; it is not specific to surgical mortality. An increasing score, from 0 to 71, correlates with mortality in a cohort of 5815 patients from 13 institutions. An APACHE II score of 30-34 resulted in 73% mortality; and 84% with a score of 35-39. APACHE II includes physiologic markers that are typically available for all ICU patients. However, completion of the tool requires all variables; there is no adjustment for missing variables. Additionally, outcomes of certain admission diagnoses (e.g. sepsis) does not correlate well will with the patients APACHE II score[4]. Knaus *et. al*. modified APACHE to more accurately predict mortality rate in hospitalized patients [3] calling it APACHE III. It does not require all variables to predict mortality. It is scored between 0 and 299; an increase of 5 points correlates to significantly higher mortality especially for scores between 20 and 140. However, the predictive strength varies with admission diagnosis[3]. The algorithm for APACHE III is not superior to APACHE II and in some specific situations, including surgical and gastrointestinal patients, is less specific than APACHE II [41]. Both APACHE II and III underestimate hospital mortality, but APACHE III does so to a greater degree. Additionally, APACHE III compares similar clinical presentations to predict risk using a proprietary database. For both these reasons we have only presented APACHE II in Table 2.

American College of Surgeons (ACS) NSQIP Mortality Predictor (NMP)[9,42] was developed from the Veterans Affairs (VA) NSQIP[8]. It assesses risk-adjusted 30-day morbidity and mortality of surgical outcomes. Validity has been demonstrated in multiple cohorts of VA patients[43], and the general public (correlation = 0.98)[44]. The ACS NMP is used for all patients 18 and older and was developed for common laparoscopic and open surgical procedures. It incorporates 35 pre-operative and operative variables to assess the probability of 30-day mortality[9]. NSQIP collects surgical outcome data from over 700 hospitals around the world. It is a robust assessment tool but cannot be used for pre-operative risk assessment and cannot be administered at the bed side[9].

The ACS NSQIP PMP was developed to permit pre-operative risk assessment for common surgical procedures[9] based on ACS NSQIP data. The PMP uses 16 objective pre-operative variables and has been validated for open pancreatic and laparoscopic/open colorectal, gall bladder and hernia surgery. The NSQIP PMP score ranges from -1 to 30 (Table 2), and it can be calculated with the ACS online tool (https://riskcalculator.facs.org/). The ROC analysis of PMP found it to be 93% accurate at predicting death and it a 86.9% correlation with NMP[9].

As a state, frailty is conceived to be an accumulation of deficits with accelerating functional decline over time. Multiple frailty screening tools have been developed. While none have been found to be superior to others[45–50], frailty has consistently been shown to be an independent predictor of morbidity and mortality[17–19,48,51] and is superior to age alone in multiple surgical populations[17,18]. In older surgical patients, frail patients had a 2 to 2.6 fold increase in complications[17,19] and significantly increased mortality rates [17]. The use of frailty in conjunction with ASA and other risk assessment tools increases the predictive ability of these tools[19]. In addition, a study of the cost of healthcare services following discharge from an acute general surgery service found age was not significant following adjustment for patient frailty measured with the Canadian Study of Health and Aging (CSHA) Clinical Frailty Scale (CFS)[52]. To date frailty assessment has not been incorporated into most surgical risk assessment tools. Two common frailty assessment tools include the CFS[50] and the Edmonton Frail Scale (EFS)[49]. Gait Speed has been shown to predict morbidity and mortality in cardiac surgery[53]. However, content validation is poor, since it captures a very narrow aspect of frailty, and is not recommended for use in the acute care setting by the National institute for Health and Care Excellence in inpatient hospital settings.

The CFS uses a 9-category scale scoring individuals based on a clinical assessment that considers co-morbidities, cognitive impairment and activities of daily living (ADL)[50] (Table 3). Individuals are rated between very fit (1) to terminally ill (9). The CFS was validated over 5 years for medical patients 65 and over; scores correlate significantly with morbidity and mortality. An increase by one category on the CFS predicts increased 6-year institutionalization (23.9%) and mortality (21.2%)[50]. The CFS also has an area under the curve (AUC) on 0.71 for 30-day mortality following cardiac surgery[54] and predicts increased 30-day (OR 4.04, p=0.04) and 90-day (OR 3.04, p=0.02) mortality in general surgery patients[55]. The score is best suited to rapid case-finding based on expert clinical impression. The main limitations are that CFS does not clearly define each category[50].

The EFS is a multidimensional syndrome-based predictor of frailty (Table 3). The frailty score has been validated in patients' 65 and older referred for comprehensive geriatric assessment[49] and before elective non-cardiac surgery[48]. The score ranges from 0 to 17 and correlates with increased morbidity and institutionalization following surgical intervention[48], and with a geriatrician's clinical impression of frailty[49]. Scoring higher than 7 predicts increased post-operative complications (OR 5.02) and lower than 4 predicts lower complications (OR 0.27). The receiver operating curve of the EFS for morbidity is significant (0.69)[48] and may better highlight aspects of frailty that are amenable to preoperative optimization[56]. The EFS can be administered in under 5 minutes and can be administered with no formal medical training[49]. The Reported EFS, where a patient reports their physical condition before their acute illness, is an alternative to the traditional EFS. The reported EFS has been validated in acute medical patients and elective non-cardiac surgical patients over 70[48,57].

The PAFS fitness index[7] is a multivariable predictor (Table 4). It was developed in patients who underwent major abdominal surgery. Appendix and hernia procedures were excluded from the validation study. The final score ranges from 0 to 10 and correlates with mortality[7]. In a cohort of 1517 consecutive patients those with PAFS scores less than 6, 102 experienced major complications (9.3%) and 7 died (0.6%), while among those with PAFS of 6 or higher there were 196 major complications (46.4%) and 160 deaths (37.9%); the sensitivity and specificity for mortality were 95.8% and 80.6% respectively.

The POSSUM scoring system[10] predicts morbidity and mortality in patients requiring inpatient surgery, excluding trauma surgery. The score is calculated in two parts: the physiologic score is based on physiologic and biochemical status and the operative severity score accounts for procedure performed and other intra-operative data (Table 4)[10]. It robustly predicts both morbidity and mortality ($p<0.001$)[10] and has been validated for emergency laparotomy[58], hip fracture[59], and a colorectal specific score has also been developed[60]. However, it profoundly over predict morbidity and mortality, particularly in those with low risk profiles[11,58,61] and nonagenarians[13]. POSSUM is also weaker at predicting mortality for non-cardiac diseases, cannot be used for trauma patients and can only be applied retrospectively. p-POSSUM was developed to address POSSUMs tendency to over-predict mortality[11] and consequently does not predict morbidity. It has been validated in emergency abdominal surgery[11,58], gastrointestinal surgery[61] and pulmonary surgery[62]. Both POSSUM and p-POSSUM use the same 18 physiologic, biochemical and perioperative parameters. Both p-POSSUM and POSSUM cannot be administered prospectively since they depend on intra-operative findings to gauge risk.

The E-PASS score was developed in gastrointestinal surgical patients[63] and subsequently validated for complications in elderly colorectal surgery patients[64], liver surgery[65] and hip fracture[66] patient groups however it should not be used in hemodialysis patients[67]. The E-PASS AUC was 0.78 for the overall model, better than for the colorectal-POSSUM and Prognostic Nutrition Index in elderly colorectal surgery patients[64]. A Comprehensive Risk Score (CRS) ≥ 0.2 significantly predicted postoperative complications (HR 4.84, p<0.01) and higher CRS score correlated with a higher probability of a severe complication (Clavien-Dindo >3)[64,66]. The E-PASS It was also able to predict mortality in patients who did not get chemotherapy, but was unable to do so in patients who had had chemotherapy. It was more effective at predicting mortality in hip fracture patients. E-PASS also requires intra-operative variables, is difficult to calculate at the bedside and requires pulmonary function testing to complete (Table 5). It also requires a performance status index score which is subjective and if it is defined in the study, uses different scales in different studies[63,64,66].

The Surgical Risk Preoperative Assessment System (SURPAS)[12] is a new internally validated risk assessment score based on NSQIP data. It is focused on the 9 most common surgical specialties (general, vascular, orthopedic, thoracic, plastic, urologic, otolaryngologic, gynecologic, and neurosurgery). It adjusts risk for emergent procedures with good predictive ability (c statistic 0.928). However, it requires the use of work relative value unit which is calculated using copyrighted American billing codes and based on an agreed estimate of time required to deliver each service or procedure. Determining each billing code for patients outside of the United States could be prohibitively time-consuming.

Surgeon expert opinion assesses risk based on surgical experience and does not rely on defined predictors of morbidity or mortality. In a study on 1077 patients, post-operative complications following major emergency or elective hepatobiliary and gastrointestinal surgery were predicted by the attending surgeon. There were 29% observed complications versus 32% predicted complications based on expert opinion[68], much better than POSSUM and p-POSSUM. The study is limited by its small sample of surgeons, the fact it did not measure predicted probability of mortality, and its comparison to POSSUM which is known to overestimate morbidity and mortality.

Other tools identified more than once that did not meet all criteria for inclusion were the Post-Operative Pulmonary Complications tool[69], which is used only to assess the risk of respiratory complications. Surgical APGAR score[70] is an easily administered tool but has not been validated in patients 65 and older (Table 6). Finally, the Mini Mental Status Exam (MMSE) and Montreal Cognitive Assessment have been used to predict post-operative delirium in the elderly.

Discussion

Appropriate risk assessment plays an integral role in providing complete and accurate information, on which a patient can base their choice of treatment. Although the use of risk assessment tools to advise patients of their adjusted risk allows them to make more informed decisions, deciding which tool to use isn't clear. There are many tools available; however, many have not been validated in the elderly or specific surgical populations, are designed to predict different outcomes and are prone to over- or under-estimation of risk. Additionally, the discriminatory power of risk prediction tools may be reduced at the extremes of age. Given the large numbers of different tools available deciding the best tool for an individual patient can be challenging. Formally validated tools allow for more consistent risk analysis however they can be cumbersome and time consuming to administer. Development of a universal rapidly administered risk assessment tool specific to the elderly for emergent and elective surgeries has so far been elusive. Consequently, clinicians most commonly default to estimating risk based on isolated clinical states, clinical judgement and experience, which is prone to high inter- and intra-observer variability[68,71].

Utility of single variable predictors of risk

Using an isolated clinical state to gauge risk is prone to significant errors. DNR status may be indicative of overall patient health, but alternatively may be an indicator of a patient's philosophy of care or institutional policy. Modern advanced care planning documents are more nuanced than in the past and more accurately represent an individual patients' unique health status and values nonetheless DNR orders have been included in larger risk assessment tools[9] and the presence of a DNR order may be attributed to a 10% increase in mortality[23]. Likewise, elective and emergent surgical status can be attributed to 20% of mortalities in nonagenarians but cannot be used alone[13].

Increasing sarcopenia has a strong correlation with morbidity and mortality[27,29,30,33]. However, assessment of sarcopenia is limited by disagreement over how to measure it, the expense of imaging equipment, need for specialized software and training expertise required to calculate total muscle area[27].

As people age, their one-year mortality rises regardless of the need for surgical intervention. However, there is conflicting evidence as to the degree with which increasing age independently predicts morbidity and mortality after controlling for other clinical parameters. Frailty actually has a much stronger association with risk[17,18] and is a more reliable predictor of surgical risk than age[18]. Overall, the use of a single clinical variable to predict the risk of surgical intervention is not advisable and should be avoided in most cases.

Implementation of multivariable risk assessment tools

Many of the current multi-variable risk stratification tools rely on postoperative data that is not available when consenting a patient for surgery, while other tools rely on laboratory and clinical values that aren't routinely collected. The current abundance of risk assessment tools that apply to small populations has created an overwhelming number of scoring systems leading to few being used consistently in clinical practice. Additionally, low awareness and lack of guidance around appropriate use all decrease uptake and implementation. Surgical expert opinion remains the most commonly used pre-operative risk assessment tool, but is entirely dependent on surgeon experience[68].

Most frailty assessments include multiple data points and often can best be conducted by clinicians trained in comprehensive geriatric assessment. The CSHA Clinical Frailty Scale (CFS) is simple to administer and has good correlation with the more thorough frailty index[50] which has been shown to predict morbidity and mortality in some surgical populations[72,73]. There has, to date, been no assessment of the CFS' ability to predict surgical morbidity. The Edmonton Frail Scale is another frailty assessment tool that has been validated in surgical populations[48] but has not yet been widely adopted in surgical practice outside of the United Kingdom. The more detailed Frailty Index[50] is time intensive to administer but has been validated in some surgical populations[72,73]. It lends itself to implementation at institutions with in depth electronic charting to automatically assess patients for frailty. The Frailty Index has been condensed to include only outcomes that are available in the NSQIP database; the modified Frailty Index (Table 1) has been shown to predict 30-day morbidity and mortality in all surgical specialties[74,75] and readmission in general, vascular and orthopedic surgery patients[76]. Overall, frailty assessment can assist with risk assessment but there is no consensus on the best frailty assessment tool.

Many new surgical risk prediction tools are being developed every year, but few are ever clinically implemented. Barriers include limited surgical population studied, resource intensive calculation methods, dependence on postoperative data for risk calculation and lack of awareness. Predictive tools can be used beyond theirs scope resulting in a loss of accuracy. For example, American Society of Anesthesiologists physical status classification (ASA) is a subjective classification system that has been shown to correlate well with mortality[2,77,78] and is incorporated into some risk assessment tools. However, prediction of mortality risk by ASA classification is strongly dependent the specific surgical procedure performed[2,79,80] and it suffers from high inter-rater variability[81]. The development of the Charlson Age Comorbidity Index was initially validated in a medical population before being validated in surgical populations[6,39,40]. It is based almost entirely on medical history and is well established in the literature but there are no tools available to predict the specific risk associated with a specific surgical intervention.

The PAFS[7] only uses pre-operative data and has acceptable sensitivity and specificity. However, it uses 26 parameters, including laboratory investigations, making calculation time consuming. It has also only been validated in general surgical procedures, has not been extensively studied since it was originally created nor has it been widely used clinically. The POSSUM tool has been specifically modified for surgical procedures including orthopedic, pancreatic, colorectal and general surgical interventions in the elderly. However, it is known to over-estimate the risk of morbidity and mortality, particularly in low risk procedures, and requires intra-operative data to measure risk of post-operative risk.

The NSQIP PMP[9] was developed specifically to allow pre-operative risk assessment without any laboratory values but has been validated for select general surgical procedures only. NSQIP PMP represents a promising tool for pre-operative risk assessment and patient consent. It can also be calculated online through the American College of Surgeons website which allows the surgeon to modify the risk prediction based on their clinical assessment of the patients' risk. SURPAS may also represent a promising tool that has been validated in more that just general surgical procedures, however it does not yet have an easily accessed calculation tool.

Expert opinion remains the most commonly used risk assessment method. In a small study it was shown to be more accurate than p-POSSUM and POSSUM at predicting morbidity[68], but was not assessed for prediction of mortality. It is, however, highly dependent on a surgeons' years of experience and surgeons were prone to more significantly under-estimating morbidity in emergency surgery. Incorporation of frailty in a clinicians' expert assessment or risk may improve their assessment. Many surgeons feel they know frailty when they see it however perceived frailty is an inadequate proxy for measured frailty[82] and the use of easily administered frailty assessment tools such as the CFS may improve expert opinion. In the future, frailty may be more appropriate than age when creating multi-variable risk assessment tools.

Recommended tools

Overall, aside from expert opinion with rapid frailty assessment using the CFS, three multi-variable tools for risk assessment are most promising. For general surgical procedures, the NSQIP PMP is a relatively easily administered tool with good predictive ability that can be adjusted based on a surgeon's clinical experience and intuition. It is the most mature and tested of the tools we identified. It presents the risk calculations divided into multiple different categories of morbidity and mortality allowing the patient to better understand the risks posed by the proposed intervention. The SURPAS tool has the potential to be a useful tool for multiple surgical specialties given is use of only 8 pre-operative variables and strong predictive strength. However, it is a new tool that has not been validated outside the study population and an online tool is still under development that would allow rapid calculation of risk[83]. Additionally, the modified Frailty Index is promising for institutions with comprehensive electronic medical records. The calculator could be built into the medical record allowing rapid risk measurement based on the included variables and the planned surgical intervention in any specialty.

Limitations

Our study is limited by the available literature, their methods and validation protocols. All studies discussed have been validated in a surgical population. However, most were validated in select general surgery populations; no examination of the predictive abilities in other surgical specialties was made. SURPAS and NSQIP PMP are notable exceptions. We have excluded assessment tools that were not used more than once in the literature. Several assessment tools we have reviewed are designed for risk adjustment when performing post-hoc assessment of outcomes. They rely on operative or post-operative data and cannot be used for clinical assessment of risk for patient consent.

Conclusion

Appropriate risk assessment is important to helping guide informed decision making as it relates to surgical procedures. Development of reliable, validated and clinically relevant surgical risk assessment tools remains challenging. NSQIP PMP is a promising tool with good discriminatory power that requires only pre-operative variables, is easily calculated with available online calculation tools and provides a clear assessment of risk across multiple clinically relevant domains. SURPAS and modified Frailty Index may also become clinically relevant due to a small number of variables and strong predictive strength for both morbidity and mortality across specialties. Frailty assessment tools, such as the Clinical Frailty Scale and the Edmonton Frailty scale, may improve expert opinion along with being surgical risk predication tools in their own right. Finally, sarcopenia has potential as an objective risk assessment method, but further research into its feasibility is required before it can be used clinically.

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Table 1: Risk assessment tools' studied population, included parameters and measured outcomes

Predictor	Study			Total # Variables	Clinical Parameter					Surgical Parameter			Outcomes			Ease of use for pre-operative risk assessment
	Population	Included patients	Major exclusion criteria		Age	Lab Values	Patient Interview or Mental Health Survey	Patient or Historical Comorbidity	Physical Assessment or Current Comorbidity	ASA Class	Surgical Details	Post-operative Course	Morbidity or Mortality	Time to outcome assessed	Predictive tool statistical strength	
APACHE 2	Medical and surgical ICU	All adult patients admitted to ICU	No exclusions	14	YES	YES	YES	YES	YES	X	X	X	Mortality	DC or death	ROC 0.863	For ICU patients only
ASA	All surgical patients	All surgical patients	None	1	X	X	X	X	YES	X	X	X	NA	NA		Easy
CACI	New York hospital medical patients	All medical patients, validated in surgical patients	Patients not admitted to the medical service	2	YES	X	X	X	YES	X	X	X	Mortality	10 years	AUC 0.9	Easy
CSHA Clinical Frailty Scale (CFS)	Home and institution dwelling seniors	70 and over	No dementia 5 years earlier	7 or 70	X	X	YES	YES	YES	X	X	X	Mortality and Institutionalization	5 years	ROC 0.77	Easy
Fitness Index - PAFS	Major abdominal surgery	Emergency and elective surgery	Appendectomy and hernia	28	YES	YES	YES	YES	YES	X	YES	YES	Morbidity and mortality	30-day	Sen 95.8%	Time consuming
modified Frailty Index	NSQIP database	All surgical patients	None	11	X	X	X	YES	YES	X	X	X	Morbidity and mortality	30-day	varies with specialty	Easy if built into EMR
Edmonton Frail Scale	65 and older	All patients referred for CGA	Communication barrier	10	X	X	YES	X	YES	X	X	X	Frailty	Geriatrician opinion	ROC 0.69	Hard - Need TUG test
ACS NSQIP PMP	NSQIP participating hospitals	Open pancreas, colorectal, hernia, or gallbladder surgery	Under 18	16	YES	X	YES	YES	YES	X	X	X	Mortality	30-day	ROC 0.93	Easy
POSSUM	Inpatient surgical procedures	Surgical admission over 24 hours	Trauma or lost to follow-up	18	YES	YES	YES	YES	YES	X	YES	X	Morbidity and mortality	6-weeks	ROC 0.96 mortality	Requires intra-operative variables
p-POSSUM	Inpatient surgical procedures	Adult inpatient general surgery	Pediatric, day surgery	18	YES	YES	YES	YES	YES	X	YES	X	Mortality	DC or death	AUC 0.84	Requires intra-operative variables
E-PASS	Inpatient surgical procedures	Gastrointestingal surgery patients	Preoperative sepsis/ SIRS	9	YES	X	X	YES	YES	YES	YES	X	Morbidity and mortality	DC or death	AUC 0.78	Hard - PFT required
SURPAS	NSQIP participating hospitals	9 most commons surgical specialties	Missing critical values, rare surgical specialty	8	YES	X	X	X	YES	YES	YES	X	Morbidity and mortality	30-day	AUC 0.928	Hard (until online tool developed)
Surgeon Expert Opinion	Major elective and emergency surgery	All adult general surgery patients	Minor surgery	1	X	X	X	X	X	X	X	X	Morbidity and mortality	30-day	Varies with experience	Easy

DC = Discharge, NA = Not applicable, CGA = Comprehensive geriatric assessment, ROC = Receiver operating characteristic, AUC = Area under the curve, SIRS = Systemic inflamatory response syndrome, ICU = Intensive Care Unit, CACI = Charlson Age Comorbidity Index, EMR = Electronic Medical Records, TUG - Timed up-and-go test, PFT = Pulmonary function testing

Table 2: Scoring algorith for NSQIP PMP, APACHE II and Charlson Age Comorbidity Index with predicted outcomes, validated populations and original citatio

Tool	NSQIP PMP	
Prediction	Morbidity and mortality	
Data source	Adult NSQIP data	
Validated in	General Surgery	
Reference	Vaid *et al* 2012	
Items		**Score**
Inpatient		6
Sepsis		4
Total assistance for ADLs		3
Disseminated cancer		1
Age, years		
80 and over		2
70-79		1
65-69		0.5
Comorbidities		
Cardiac		5
Pulmonary		3
Renal		1
Liver		1
Chronic steroid Rx		1
Weight loss (>10% in 6 months)		1
Bleeding disorder		1
Do Not Recussitate		1
Obesity		-1
Total		30

APACHE II					
Mortality					
13 hospital ICU admission					
All ICU admission including non-operative					
Knaus *et al* 1985					
Score	**0**	**1**	**2**	**3**	**4**
Temperature (°C)	36-38.4	34-35.9 or 38.5-38.9	32-33.9	30-31.9 or 39-40.9	≥41 or ≤29.
Mean art pressure	70-109		50-69 or 110-129	130-159	≤49 or ≥160
heart rate	70-109		55-69 or 110-139	40-54 or 140-179	≤39 or ≥180
respiratory rate	12-24	10-11 or 25-34	6-9	35-49	≤5 or ≥50
Oxygenation (FiO2≥0.5 = DaDO2)	<200		200-349	350-499	≥500
(FiO2<0.5 = PaO2)	>70	61-70		55-60	<55
arterial pH	7.33-7.49	7.5-7.59	7.25-7.32	7.15-7.24 or 7.6-7.69	7.15 or ≥7.
serum sodium (mmol/L)	130-149	150-154	120-129 or 155-159	111-119 or 160-179	110 or ≥18
serum potasium mmol/L	3.5-5.4	3-3.4 or 5.5-5.9	2.5-2.9	6-6.9	<2.5 or ≥7
serum creatinine (mg/100mL)*	0.6-1.4		<0.6 or 1.5-1.9	2-3.4	≥3.5
hematocrit (%)	30-45.9	46-49.9	20-29.9 or 50-59.9		<20 or ≥60
White blood count (in 1000s)	3-14.9	15-19.9	1-2.9 or 20-39.9		<1 or ≥40
	APACHE II modifiers				
Glasgow Coma Scale	15 minus measured CGS score				
Age	45-54 = 2	55-64 = 3	65-74 = 5	≥ 75 = 6	
Surgery	Emergent = 5	Elective = 2			
*double if acute kidney injury					
Total	71				

Charlson Age Comorbidity Index	
1-year mortality	
Retrospective database review	
General and orthopedic surgery	
St-Louis *et al* 2015	
Score	**Sum all conditions present with score**
1	Miocardial infarction
	Cogensitive heart failure
	Peripheal vascular disease
	Dementia
	Chronic obstructive pulmonary disease
	Connective tissue disease
	Ulcer disease
	Mild liver disease
	Diabetes
2	Hemiplegia
	Moderate/severe renal disease
	Diabetes with end-organ dysfunction
	Any tumour
	Leukemia
	Lymphoma
3	Moderate/severe liver disease
	Metastatic solid tumour
6	Aquired ummune deficiency syndrome
1	for each decade over 40 years

Tabel 3: Clinical Frailty Scale and Edmonton Frail Scale scoring algorithm with predicted outcomes, validated populations and citatio

Tool	Clinical Frailty Scale	
Prediction	5-year mortality and insitutionalization	
Data source	Prospective CSHA study, retrospective surgical data	
Validated in	No surgical validation	
Reference	Drummond *et al* , 2005	
Score*		Activity level and disease burden
1	Very fit	Robust and very active
2	Well	No active disease, occasionally active
3	Managing well	Medical problems, not active
4	Vulnerable	Not dependent, symptoms limit activities
5	Mildy frail	help with high order IADLs
6	Moderately frail	Need help with bathing/keeping house
7	Severly frail	Dependent for personal care
8	Very severly frail	Dependent and at risk of death from minor illness
9	Terminally ill	Life expectancy <6 months despite activity

*For complete category descriptions, see: http://geriatricresearch.medicine.dal.ca/clinical_frailty_scale.htm

Edmonton Frail Scale			
Post-operative morbidity			
Prospective elective surgery			
Elective non-cardiac surgery			
Rolfson *et al* , 2006 and Dasgupta *et al* , 2009			
Item	0 points	1 point	2 points
clock drawing	No error	Spacing error	other errors
Hospital admissions in 1 year	0	1-2	>2
Overall health	> Fair	Fair	Poor
Assistance with IADLs	0-1	2-4	5-8
Reliable social support available	Always	Sometimes	Never
5 or more prescribed medications	No	Yes	
Do you forget to take medications	No	Yes	
Weight loss (loose clothes)	No	Yes	
Urinary incontinence	No	Yes	
Often feel sad or depressed	No	Yes	
Timed up and go test	0-10 sec	11-20 sec	>20 sec or refused

IADL: Instrumental activity of daily living (meal prep, shopping, transport, telephone, housekeeping, laundry, finances, taking Rx)

modified Frailty Index		
30-day morbidity and mortality		
NSQIP cardiac, general, gynecology, neurosurgery, orthopedic, otolaryngology, plastic, thoracic, urology, and vascular surgery 2005-2009		
Velanovich *et al* , 2013		
Medical history includes:	0 point	1 point
Diabetes melitus	No	Yes
Functional status index (partial/complete dependence	No	Yes
Chronic obstructive pulmonary disease/Pneumonia	No	Yes
Congestive heart failure	No	Yes
History of Miocardial infarction	No	Yes
Hypertension requiring medication	No	Yes
Peripheral vascular disease or ischemic rest pain	No	Yes
Impared sensorium	No	Yes
transient ischemic attack/stroke	No	Yes
stroke with neurological deficit	No	Yes
Percutaneous coronary intervention/stent/angina	No	Yes

Sum of points divided by 11 = mFI
See Velanovich *et al* , 2013 for specilty specific stepwise risk adjustment

Table 4: PAFS and POSSUM/p-POSSUM scoring algorithm with predicted outcomes, validated populations and citation

Tool	PAFS	POSSUM/p-POSSUM				
Prediction	In hospital morbidity and mortality	Post-operative morbidity and mortality/ mortality				
Data source	Prospective surgical study	Prospective general surgery				
Validated in	General surgery	General surgery, pancreatic surgery/ General surgery, hip fracture, colorectal surgery				
Reference	Playforth et al 1987	Copeland *et al* 1991/ Prytherch et al 1998				
Score	Sum all conditions present with score	**Physiologic score**	1	2	4	8
	Medically managed cardiac symptoms	Age	≤ 60	61-70	≥ 70	
	Short of breath climing stairs	Cardiac signs	No failure	Rx therapy	anticoagulant, peripheral edema or ?cardiomegaly	Raised JVP, cardiomegaly
	Morning cough					
	Stroke/miocardial infarct >6 months ago	Respiratory history	No dyspnea	exertional dyspnea, mild COAD	Dyspnea on 1 flight of stairs, moderate COAD	Dyspnea at rest (≥30/min), fibrosis/consolidation
1	Haemoglobin <10g/dl					
	Serum albumin 30-35g/L	Systolic blood pressure	110-130	100-109 or 131-170	90-99 or > 170	< 90
	Plasma urea 10-19 mmol/L	Pulse	50-80	40-49 or 81-100	101-120	< 40 or > 120
	Chronic steroids	GCS	15	12-14	9-11	< 9
	Uncomplicatied diabetes	Haemoglobin (g/100mL)	13-16	11.5-12.9 or 16.1-17	10-11.4 or 17.1-18	< 10 or > 18
	Age 70-79	White cell count	4-10	3.1-4 or 10.1-20	≤ 3.0 or > 20	
2	Poorly controled cardiac symptoms	Urea (mmol/L)	≤ 7.5	7.6-10	10.1-15	> 15
	Short of breath walking	Sodium (mmol/L)	> 135	131-135	126-130	< 126
	Persistent cough with sputum	Potassium (mmol/L)	3.5-5	3.2-3.4 or 5.1-5.3	2.9-3.1 or 5.4-5.9	≤ 2.8 or ≥ 6.0
	Clinical jaundice	Electrocariogram	Normal		atrial fibrilation (rate 60-90)	Arythmia, ≥ 5 ectopics, Q or ST/T changes
	Serum albumin <30g/L					
	10% weight loss in one month	**Operative score**				
3	Short of breath at rest	Operative severity score	Minor	Moderate	Major	Major+
	Micardial infact within 6 months	Multiple procedures	1		2	> 2
	confusion	Total blood loss (mL)	≤ 100	101-500	501-999	≥ 1,000
	cytotoxic treatment	Peritoneal soiling	None	Serous fluid	Local pus	bowel content, pus or blood
	Age > 80 years	Malignancy	None	Primary only	Nodal metastasis	Distant metastases
	palliative cancer surgery	Urgency	Elective		Emergent (> 2 hours)	Emergent (< 2 hours)
	intestinal obstruction	POSSUM morbidity formula:	ln [R/(1−R)] = −5.91 + 0.16 × physiological score + 0.19 x operative score			
4	perforations, pancreatitis and intraperitoneal	POSSUM mortality formula:	ln [R/(1−R)] = −7.04 + 0.13 × physiological score + 0.16 x operative score			
	abscess (excluding appendicitis)	p-POSSUM mortality formula:	ln [R/(1−R)] = −9.37 + 0.19 × physiological score + 0.15 x operative score			
	transfusion		R = predicted risk or morbidity or mortality			

Table 5: E-PASS scoring algorithm with predicted outcomes, validated populations and citation

Tool	E-PASS	
Prediction	Post-operative morbidity and mortality	
Data source	Prospective surgical patients	
Validated in	General surgery, hip fracture, liver, colorectal surgery	
Reference	Haga et al 1999	
Item	constant	Score
Age	0.00345	age (integer)
Heart disease (NYHA > 2)	0.323	NYHA > 2 = 1
Pulmonary disease (FEV1<50% or VC < 60%)	0.205	FEV1<50% = 1
Diabetes	0.153	Diabetes = 1
Performance status	0.148	Good to Poor (0 to 4)
ASA	0.0666	ASA = 1-5
PRS = -0.0686 + Sum product		
Blood loss/body weight	0.0139	g blood/weight (kg)
operation time	0.0392	hours on operating room
extent of skin incision	0.352	laparotomy/thoracotomy = 1 laparotomy+thoracotomy = 2
SSS= -0.342 + sum product		
CRS= -0.328 + 0.936(PRS) + 0.976(SSS)		

FEV = Forced expiratory volume; NYHA = New York Heart Association; ASA = American Society of Anesthesiologists; PRS = Preoperative risk score; SSS = Surgical stress score; CRS = Comprehensive risk score

Table 6: Surgical APGAR score algorithm with predicted outcomes, validated populations and citation

Tool	Surgical APGAR					
Prediction	Post-operative morbidity and mortality					
Data source	Retrospective surgical patients					
Validated in	General and vascular surgery					
Reference	Gawande *et al* 2007					
Item		0 points	1 point	2 points	3 points	4 points
Estimated blood loss (mL)		> 1,000	601-1,000	101-600	≤ 100	
Lowest mean arterial pressure (mmHg)		< 40	40-54	55-69	≥ 70	
Lowest heart rate		> 85	76-85	66-75	56-65	≤ 55

Highlights

- The majority of risk assessment tools developed are not commonly used
- NSQIP-PMP, modified Frailty Index and SURPAS are promising assessment tools
- The use of frailty assessment during risk assessment may better predict outcomes
- Frailty should be incorporated into future risk assessment tools for the elderly