THE SIMPLIFIED SURGICAL SITE EVENT RISK ASSESSMENT (SSERA) MODEL

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Tel: +44 (0)20 3735 8244
Email: info@omniamed.com
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FOREWORD

Despite advances in surgical techniques, implants, anaesthetic practices and the use of prophylactic antibiotics, unplanned surgery-related events such as surgical site infections (SSI) remain a challenge in clinical practice and a significant burden on healthcare systems. In the United States, annual SSI incidence rates range from 160,000 to 300,000, and the financial burden has been estimated to range from $3.5 billion to $10 billion per year (Ban et al, 2017).

In this document, we discuss the development of a universal risk assessment tool for all patients undergoing major surgery. This tool has been developed through a review of published research data. It is envisaged that the use of this tool in practice will provide a practical and pragmatic solution for identifying less obvious at-risk patients. In addition, where possible, risk can be mitigated (e.g. smoking cessation and blood sugar control etc.). The goal is to reduce surgical care-related surgical site events (SSE) while remaining clinically appropriate and cost-effective.

The objectives of this risk assessment tool are to:

- Identify risk factors that can be applied to a model to screen for gross risk common to all major surgical procedures
- Provide an objective foundation to inform decision-making on incision care practices that may have a positive influence on reducing surgical site complications.

AUTHORS

Rhidian Morgan-Jones (Chair), Consultant Orthopaedic Surgeon, University Hospital Llandough and Cardiff Knee Clinic, Cardiff, UK

Michael Bishay, Consultant Orthopaedic Surgeon, Royal United Hospital, Bath, UK

José A. Hernández Hermoso, Chairman Orthopaedic Surgery and Traumatology, Assistant Professor UAB, Germans Trias I Pujol University Hospital, Barcelona, Spain

John C. Lantis, Site Chief and Professor of Surgery, Icahn School of Medicine, Mount Sinai West Hospital, New York City, New York, USA

James Murray, Lead Knee Surgeon, Avon Orthopaedic Centre, Southmead Hospital, University of Bristol and Knee Specialists Bristol, UK

Jorma Pajamaki, Consultant Orthopaedic Surgeon, Pihlajalinna Group, Pirkanmaa, Finland

Antonio Pellegrini, Consultant Orthopaedic Surgeon, Istituto Ortopedico Galeazzi, Centre for Reconstructive Surgery and Osteoarticular Infections, Milan, Italy

Samih Tarabichi, Consultant Orthopaedic Surgeon and Chairman, Tarabichi Centre of Joint Surgery, Alzahra Hospital, Dubai, United Arab Emirates

Christian Willy, Professor of Surgery and Head of Department, Trauma & Orthopaedic Surgery, Septic & Reconstructive Surgery, Research and Treatment Centre for Complex Combat Injuries, Wound Centre Military Hospital Berlin, Bundeswehr Hospital, Berlin, Germany

ADDITIONAL RESEARCH

Brian Andrews, Global Marketing Manager, Negative Pressure Wound Therapy

BACKGROUND

WHAT IS RISK ASSESSMENT AND WHY IS IT NEEDED?

The fundamental premise of risk assessment is to take into account each individual patient's unique circumstances and characteristics. In doing so, through a simple but thorough evaluation, actions and interventions to reduce risk can be implemented, and subsequent outcomes measured.

HOW CAN RISK ASSESSMENT BE INCORPORATED INTO PRACTICE?

There is general agreement that the use of standardised assessment tools has an important role to play in guiding risk reduction. Structured and recorded risk assessment forms the basis for engagement with patients in a dialogue centred on risk and the contribution they can make to improve their condition through amendment of modifiable risk factors. Such initiatives should highlight that everyone involved in the care of the patient shares a common view of the individual patient's risk profile and, if necessary, take steps to reduce risk at every point in the patient's journey.

Crucially, there is a need for risk assessment tools that balance accuracy with pragmatic simplification that will help to inform the care that patients need, based on their individual risk factors. In context, from an initial 72 candidates, 20 core risks factors and associated multipliers were identified (Morgan-Jones et al, 2020). An example of one of these risk factors identified was diabetes, where influence on surgical site complication (SSC) risk would increase based on glycaemic control status (e.g. normoglycemic/hyperglycaemic). This progression logic was applied to all 20 core risks factors, and the resulting algorithm delivered more than 100 variables that would require digitisation to produce a model that could be considered for practical use in a clinical setting; however, while digitisation is often recommended as the ideal solution to resolve complexity, its implementation is both costly and time-consuming.

WHAT IS THE SURGICAL SITE EVENT RISK ASSESSMENT (SSERA) FRAMEWORK?

While there is unlikely to be one universal truth applicable in all circumstances, we have identified those risk factors that are most frequently cited and evidenced as having independent predictive validity in the risk of SSI. Further, we have considered a framework based on six risk factors that provides relevant guidance in the care of the incision site.

Simplicity is an important consideration that can influence adoption and routine use; however, care needs to be taken to ensure that important risk factors are not overlooked for the sake of convenience or brevity. Accordingly, in preparing this model, we have paid particular attention to existing validated tools and to creating a framework that lends itself to future digitisation, which will enable users to take account of factors specific to various surgeries. In this document, we focus on factors consistently identified as independent predictors of risk and supported by evidence that risk will be increased regardless of the procedure.

HOW WAS THE SSERA RISK ASSESSMENT FRAMEWORK DEVELOPED?

Studies indexed in PubMed were identified through the following search terms:

- Surgical site infection
- Risk factors
- Surgical risk factors
- Surgical site risk assessment.

A total of 1,059 abstracts were found, from which 20 validated surgical site risk assessment tools were identified. It is through an assessment of these tools that we developed the risk assessment framework.

For clarity and ease of use, we classify risk as being either:

- Intrinsic (patient-related)
- Extrinsic (procedure-related).

Above all, we would advocate that risk assessment is an essential requirement to balance the equation of clinical benefit and economic impact when considering risk reduction initiatives, such as in the case of incision care. Identification of a high-risk patient who is likely to benefit from intervention is likely to improve clinical and economic outcomes in the long term.

In our first publication **(Morgan-Jones et al, 2020)** on the topic of unplanned SSEs and the development of a practical risk assessment tool, we undertook an extensive research programme identifying >1,000 publications discussing SSI, risk factors, surgical risk factors, and/or surgical site risk assessment. From an initial 72 candidates, we confirmed 20 core risk factors and defined some 120 multipliers, delivering an algorithm that would serve as the foundation for a risk assessment model. Focus was shifted to usability, with the realisation that, while a complex evidence-based algorithm would likely deliver a high degree of fidelity, in practice such a model would be unrealisable in anything other than a digital form.

In this paper, we revisited the surgical site event risk assessment (SSERA) model and reviewed 20 existing validated tools, to determine if they can yield a subset of risk factors that can be put to practical use in a simplified model, without losing the intent and integrity of earlier research.

EXISTING RISK ASSESSMENT TOOLS

We identified 20 risk assessment tools, the majority of which were either surgical discipline and/or procedure-specific, hence some risk factors are unsurprisingly specific to disease and procedure and arguably relevant only in that application [Table 1]. Accordingly, we have focused on the factors identified that may apply regardless of discipline or procedure and where there is general agreement in respective usefulness and validity.

For further details of existing risk assessment models, the full review can be seen in Appendix 1 (page 13). Box 1 provides a summary of the most frequently identified risk factors.

Table 1. Existing risk assessment models

Reference	Surgical discipline	Number risk factors	Prediction
Berbari et al, 2012	Orthopaedic	6	Prosthetic joint infection
Everhart et al, 2016	Orthopaedic	17	Prosthetic joint infection
Anatone et al, 2018	Orthopaedic	6	Prosthetic joint infection
Tan et al, 2018	Orthopaedic	17	Prosthetic joint infection
Culver, 1991	Non-specific	3	Surgical site infection
Anaya et al, 2012	Oncologic	5	Surgical site infection
Berger et al, 2013	Colorectal	6	Surgical site infection
van Walraven and Musselma, 2013	Non-specific	13	Surgical site infection
Karellis et al, 2015	Non-specific	5	Surgical site infection
Raja et al, 2015	Cardiac	6	Surgical site infection
Wiseman et al, 2015	Vascular	14	Surgical site infection
Bustamante-Munguira et al, 2019	Cardiac	2	Surgical site infection
Magboo et al, 2020	Cardiac	6	Surgical site infection
Namba et al, 2020	Spinal	5	Surgical site infection
Lubelski et al, 2021	Spinal	5	Surgical site infection
Papadopoulos et al, 2021	Trauma	4	Surgical site infection
Pepin et al, 2020	Obstetric and gynaecological	7	Surgical complication
Friedman et al, 2020	Cardiac	2	Cardiac perforation
Bohl et al, 2019	Orthopaedic	6	Early adverse events in ankle fractures
Paxton et al, 2015	Orthopaedic	7	Failure of knee and hip arthroplasty
Fowler et al, 2005	Cardiac	12	Major infection
Protopapa et al, 2014	Non-specific	6	Increased mortality risk

THE SSERA RISK ASSESSMENT FRAMEWORK

Box 1. Most frequently identified risk factors

- Intrinsic risk factors: body mass index (BMI); diabetes; American Association of Anaesthesiologists score; female gender; tobacco use; age; chronic obstructive pulmonary disease (COPD)
- Extrinsic risk factors: procedure duration; wound classification; surgical urgency.

We have identified those risk factors that are most frequently cited and evidenced as having independent predictive validity in the risk of SSEs. Furthermore, we considered a framework based on 6 risk factors that provide relevant guidance in postoperative incision care.

THE RISK FACTORS

Intrinsic risk factors

Obesity

There are three classes of obesity (CDC, 2022):

- BMI ≥30–34.9 (Class I)
- BMI ≥35–39.9: (Class II)
- BMI ≥40 (Class III).

While there are conflicting views around the degree of obesity that signals the onset of increased risk, Class III (morbid obesity) is most often identified as an independent predictor of risk. 68% of existing models identify obesity regardless of class as a risk factor for SSEs. In the SSERA model, obesity combines with other risks as a compounding factor; therefore, obesity alone does not result in a high-risk classification but may contribute to one when combined with other factors.

Diabetes

Affecting approximately 537 million adults worldwide in 2021, diabetes is a worsening pandemic and is projected to affect 643 million people by 2030 and 783 million people by 2045 (The International Diabetes Federation, 2021).

While glycaemic control is considered a factor, there are conflicting views on the relationship between elevated blood glucose and HbA1c levels (Pomposelli et al, 1998; Iorio et al, 2012; Adams et al, 2013; Mejia et al, 2014; Martin et al, 2016; Kremers et al, 2017; Liqing et al, 2017; Yang et al, 2017) and increased risk for SSI and other complications. Nonetheless, diabetes has significant health consequences, and the relationship between diabetes and increased risk for SSI is widely recognised, leading to increased morbidity, mortality, length of hospital stay, and healthcare costs (Totty et al, 2020). Accordingly, 55% of existing validated models identify the disease as a significant contributor to risk. In the SSERA model, diabetes does not result in a high-risk classification but will contribute to increased risk when combined with other factors.

ASA (American Society of Anesthesiologists) Physical Status Classification System

The intended purpose of this system, which has been in use for over 60 years, is to assess and communicate a patient's pre-anaesthesia medical comorbidities (ASA, 2014; Table 2). The system does not predict risk as a standalone model; however, the scope of patient assessment is such that many independent predictors are considered. It could be argued that ASA is the enabler for simplification of risk assessment, and many of the risk factors individually excluded are in fact embraced within this model. 41% of existing validated tools identify a worsening ASA score (U3) as a significant contributor to risk for SSI.

In the SSERA model, ASA combines with other factors to compound risk. ASA U III includes one or more moderate to severe diseases. Examples include (but are not limited to): poorly controlled diabetes or hypertension, chronic obstructive pulmonary disease (COPD), morbid obesity (BMI >40), active hepatitis, alcohol dependence or abuse, implanted pacemaker, moderate reduction of ejection fraction, end-stage renal disease undergoing regularly scheduled dialysis, premature infant post conceptual age < 60 weeks, history (>3 months) of myocardial infarction, stroke/transient ischaemic attack, or coronary artery disease/stents.

Extrinsic risk factors
The Association of periOperative Registered Nurses (AORN) incision classification system (Garner, 1985) is used frequently to stratify patients based on SSI risk [Table 3]. There are four classes: clean closed, clean-contaminated, contaminated, and dirty infected.

In the SSERA Risk Assessment Framework, regardless of other risk factors, Class III and IV wounds result in a high-risk outcome. Class II wounds combined with any two intrinsic or extrinsic risk factors will result in a high-risk classification, whereas Class I wounds do not increase risk when combined with other risk factors. 23% of existing models identify wound classification as a predictor of risk for surgical site events.

Table 2. ASA Physical Status Classification

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

Table 3. Wound classification

Clean (I)	Clean-contaminated (II)	Contaminated (III)	Dirty or Infected (IV)
Infection Risk 2% or lower	**Infection Risk 4% to 10%**	**Infection Risk >10%**	**Infection Risk >25%**
An incision in which no inflammation is encountered in a surgical procedure, without a break in sterile technique, and during which the respiratory, alimentary or genitourinary tracts are not entered (e.g. surgical wound following primary closure –hernia, varicose veins)	An incision through which the respiratory, alimentary, or genitourinary tract is entered under controlled conditions but with no contamination encountered (e.g. surgical wound at risk of infection due to location – elective cholecystectomy)	An incision undertaken during an operation that results in a major break in sterile technique or gross spillage from the gastrointestinal tract, or an incision in which acute, non-purulent inflammation is encountered (e.g. surgical wound - elective colorectal). Open traumatic wounds that are more than 12 to 24 hours old also fall into this category	An incision undertaken during an operation in which the viscera are perforated or when acute inflammation with pus is encountered (e.g. emergency surgery for faecal peritonitis), and for traumatic wounds if treatment is delayed, there is faecal contamination, or devitalised tissue is present (e.g. burns, diabetic foot ulcers – drainage of abscess, faecal peritonitis)

Procedure classification
While the terminology describing the degree of surgical urgency is by no means standardised (e.g. elective, urgent, emergency – expedited, urgent, immediate – elective, emergency), the degree of surgical urgency is acknowledged by 18% of existing validated models as increasing the risk of SSEs.

An elective surgery or elective procedure is surgery that is scheduled in advance because it does not involve a medical emergency. Urgent surgery can wait until the patient is medically stable but should generally be done within 2 days. Emergency surgery must be performed without delay; the patient has no choice other than immediate surgery if permanent disability or death is to be avoided. In the SSERA model, an emergency procedure returns an immediate high-risk classification regardless of any other risk factor.

Duration (>or=75th percentile)

The duration of operative procedures under general anaesthetic is widely discussed and considered an independent risk factor for post-operative morbidity and mortality, with many authors considering the relationship between operative time and SSI. (Vernet et al, 2004; Leong et al, 2006; Boston et al, 2009; Gibbons et al, 2011; Yimeng et al, 2015; Cvijanovic et al, 2019; Xu et al, 2019; van Niekerk et al, 2020).

Derived originally from the US National Nosocomial Infections Study (NNIS), through analysis of procedure durations and related outcomes it was determined that risk for SSI becomes significant in operations that extend beyond the 75th percentile for the given procedure. Expressed as the cut point T when rounded to the nearest whole number of hours, to distinguish between short and long duration operations, one study on total joint arthroplasty surgery demonstrated the relevance of the model where with each fifteen-minute increase in operative time it was found to be associated with a 9% (95% CI, 4% to 13%) increase in the risk of deep SSI (Namba et al, 2020). Similarly, a meta-analysis demonstrated that the likelihood of developing a complication increased with increasing operative time increments (i.e., 1% for every 1-minute, 4% for every 10-minute, 14% for every 30-minute, and 21 % for every 60-minute increase in operative time; Cheng et al, 2018).

While widely recognised as the benchmark model for assessing risk associated with procedure duration, determining the 75th percentile is reliant on surveillance data. Other researchers have sort to determine a singular timeframe that infers risk regardless of specific procedure duration boundaries. In an evaluation of non-colorectal abdominal surgeries, post-operative infection rates of 6.3% for 1 hour, 12.2% for 1-2 hours and more than doubling to 27.7% for procedures longer than 2 hours were identified (Pessaux et al, 2003). In their (Daley et al, 2015) analysis of ACS NSQIP data of multiple surgical disciplines and procedures, the Tennessee Surgical Quality Collaborative observed that risk of organ-space SSIs began at 42 minutes of operative time while risk for all post operative occurrences began at 2.1 hours. In their meta-analysis, Cheng et al (2018) confirmed that operative duration was associated with a statistically significant increase in complications. Through their pooled analysis of multiple surgical disciplines and procedures, it was identified that the likelihood of experiencing a complication approximately doubled with operating times exceeding 2 hours.

Duration and risk is a complex association where in the context of a pre-operative risk assessment model, the notion of a singular duration cut point is attractive in universality and simplicity; however, it is clear that shorter duration procedures that exceed the 75th percentile carrying an increased risk burden would be overlooked. Accordingly, in the SSERA risk assessment model, we include two duration parameters: >75th percentile and >120 minutes. The difference in respect of risk determination is that a pre-operative assessment, where the procedure is known to be greater than 120 minutes, would immediately impact risk burden and status, whereas with a shorter procedure, final risk status would be determined after the procedure. In practical terms, in a post-operatively assessed standard risk case, the addition of >75th percentile would adjust risk to elevated, while in a case assessed as elevated risk, the addition of >75th percentile would adjust risk to high, with corresponding support considerations [Figure 1].

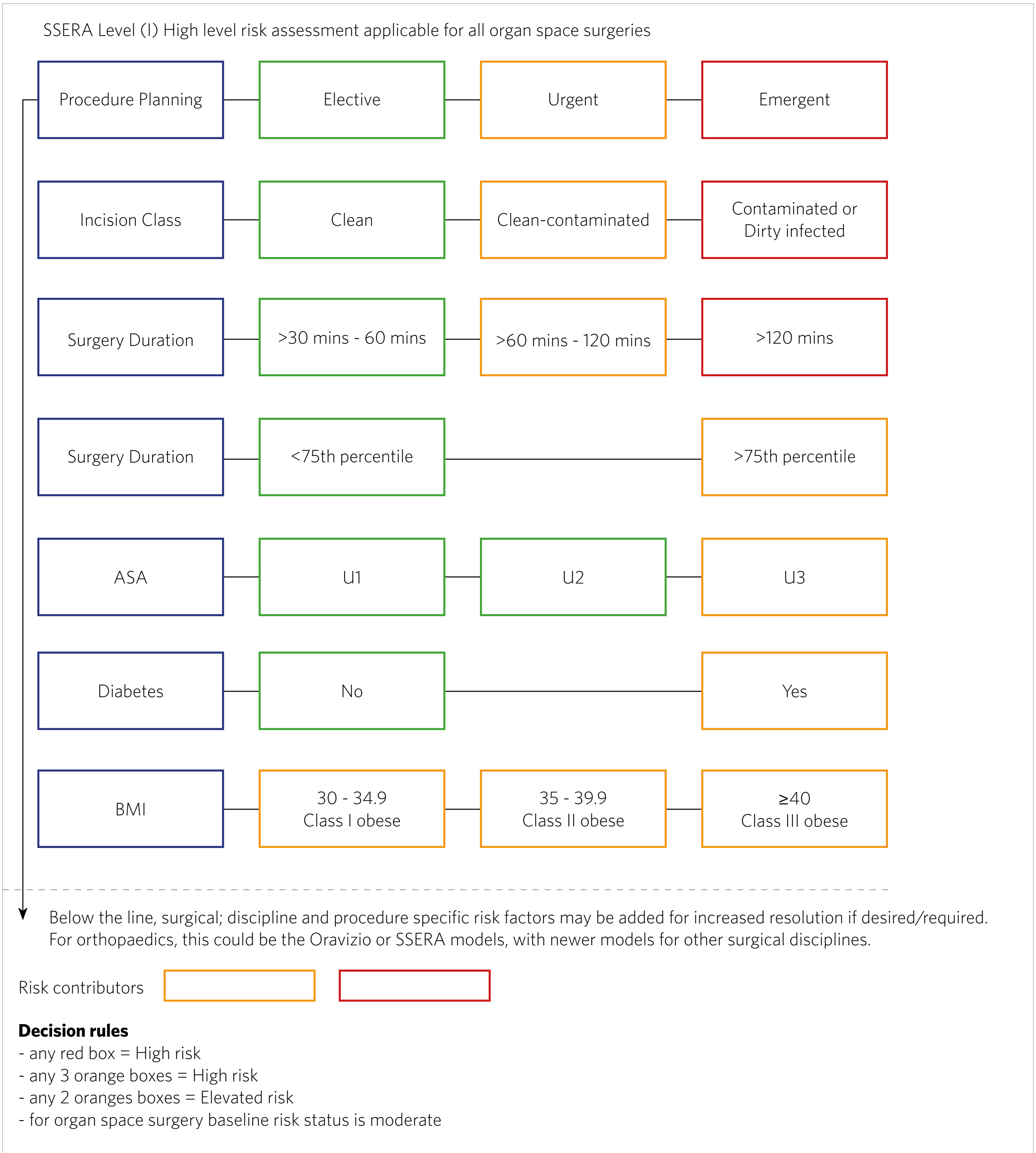


Figure 1. The SSERA assessment model

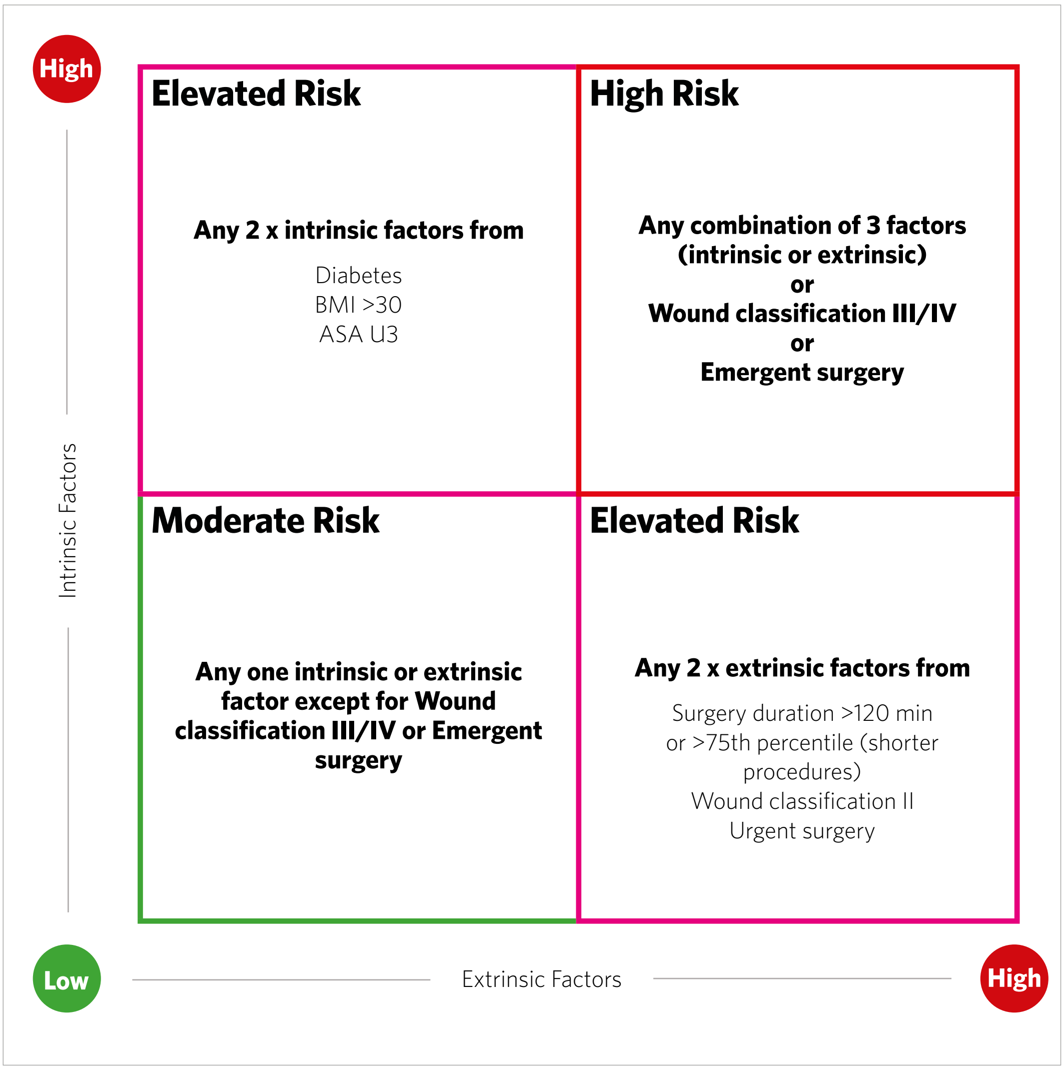
THE SIMPLIFIED SSERA MODEL FOR USE IN PRACTICE

For ease of use in practice, the simplified SSERA model uses key risk factors to assess patient risk in a way that balances accuracy with achievability [Figure 2]. For example, using the patient's ASA score is a way to incorporate risk assessment into existing models without increasing the clinical team's workload.

This model illustrates three intrinsic risk factors (vertical axis: diabetes, obesity, BMI >30 and ASA score ≥3), and three extrinsic risk factors (horizontal axis; surgical urgency, wound classification, and procedure duration).

Above all, we advocate that risk assessment is an essential requirement to balance the equation of clinical benefit and economic impact when considering risk reduction initiatives, such as in the case of incision care. Identification of a high-risk patient who is likely to benefit from intervention is likely to be clinically appropriate and cost-effective in the long term.

Figure 2. Intrinsic and extrinsic risk factors



DISCUSSION

In developing the model described, it is acknowledged that there is a good deal of endeavour in this area, and a number of existing and validated risk assessment models are currently available and in use; however, there is no clear consensus other than the need for standardised and routinely undertaken assessment. The proposed model considers the burden of comorbidities that combine to increase risk through the inclusion of other models (e.g. ASA and wound classification). The model described is both practical and implementable; however, there are limitations in respect to the specific identification of a number of known risk factors. Nonetheless, the risk assessment model does not take a singular approach and instead invites consideration for various decisions, allowing amber and red flags to be raised and further scrutiny to be undertaken where appropriate.

However, there are some immediate considerations that can be derived from the outputs of a simplified model, which in the first instance include institutional learning and the development of risk profiles that accompanies use of a standardised assessment. Furthermore, rather than the burden of assessment residing solely with the surgeon, other healthcare professionals involved in the patient's surgical journey can undertake or at least contribute to the assessment, ensuring that everyone involved in the patient's care is equally aware of the patient's risk status and the role they can play in mitigation activities. In regard to mitigation activities, standardised and routine patient population risk assessment should also raise awareness and facilitate the implementation of risk factor modification activities, such as blood sugar control and smoking cessation, which are relevant in the case of elective surgeries.

As well as reducing the incidence of complications, surgical site complication (SSC) risk assessment serves as a practical assistance in the specific use of more costly risk mitigation interventions, such as the use of closed incision negative pressure (ciNPT). While some single factor models, such as BMI, are conveniently simple, they can place too many patients in the high risk category and therefore increase costs beyond the capacity of healthcare systems. Risk assessment for SSC should consider the most appropriate incision care interventions for patients, including standard risk who are not without risk for complications, (e.g. blisters) and contamination of the surgical site if managed with inappropriate or ineffective solutions.

In summary, this publication describes a practical risk assessment tool that helps clinicians reduce the incidence of preventable surgical site complications. Further research is needed, and in subsequent publications, we will discuss the implementation and validation of the model described and its overall application of strategies to address the high-risk patient.

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APPENDIX 1: OVERVIEW OF EXISTING MODELS

MODELS FOCUSED ON ORTHOPAEDIC PROCEDURES

Development and evaluation of a preoperative risk calculator for periprosthetic joint infection following total joint arthroplasty (Tan et al, 2018)

Key points:

- The purpose of this study was to create a preoperative prosthetic joint infection (PJI) risk calculator for assessing a patient's individual risk of developing: any PJI, PJI caused by *Staphylococcus aureus,* and PJI caused by antibiotic-resistant organisms
- A total of 42 risk factors, including patient characteristics and surgical variables, were evaluated with a multivariate analysis in which coefficients were scaled to produce integer scores; of the 42 risk factors studied, 25 were found not to be significant risk factors for PJI
- The rates of PJI were 0.56% and 0.61% in the lowest decile of risk scores and 15.85% and 20.63% in the highest decile.

Risk factor	Points
BMI (kg/m^2)	(0.0865 x BMI^2) – (5.072 x BMI) + 74.35
Male	18
Government insurance	7
Total hip arthroplasty (THA), primary	18
Total hip arthroplasty (THA), revision	50
Total knee arthroplasty (TKA), primary	28
Total knee arthroplasty (TKA), revision	81
Both THA and TKA revision	87
1 prior procedure	60
2 prior procedures	87
U3 prior procedures	100
Drug abuse	62
Human immunodeficiency virus (HIV)/acquired immunodeficiency syndrome (AIDS)	49
Coagulopathy	38
Renal disease	35
Psychosis	31
Congestive heart failure	31
Rheumatologic disease	30
Deficiency anaemia	19
Diabetes mellitus	19
Liver disease	17

The Mayo Prosthetic Joint Infection Risk Score: Implication for surgical site infection reporting and risk stratification (Berbari et al, 2012)

Key points:

- The goal of this study was to develop a prognostic scoring system for the development of PJI that could risk-stratify patients undergoing total hip (THA) or total knee (TKA) arthroplasties
- The study concluded that the baseline score might help with risk stratification in relation to public reporting and reimbursement, as well as targeted prevention strategies in patients undergoing THA or TKA
- The application of the 1-month-postsurgery PJI risk score to patients undergoing THA or TKA might benefit those undergoing workup for PJI.

Risk factor	Points
Female sex	
BMI (kg/m^2) <25 25 – 30 31 – 39 >40	 0 -3 -3 0
Diabetes	
Prior other operation	2
Prior arthroplasty	3
Immunosuppression	3
ASA score 1 2 3 4	 0 1 3 9
Antibiotic surgical prophylaxis	
Urinary tract infection	
Procedure time, hours <2 2-3 3-4 >4	 0 -2 -1 2

Validated risk-stratification system for prediction of early adverse events following open reduction and internal fixation of closed ankle fractures (Bohl et al, 2019)

Key points:

- The purpose of this study was to develop and validate a risk stratification system for the occurrence of early adverse events among patients treated with open reduction and internal fixation (ORIF) for a closed fracture of the ankle
- The occurrence of early adverse events following ORIF for closed ankle fractures was associated with the risk factors included in the model
- This was used to develop and validate a simple point-based risk-stratification system to predict the risk of early adverse events.

Risk factor		Points
Greater age	40 – 59 years	1
	60 – 79 years	3
	80 years or over	5
Female sex		1
Chronic obstructive pulmonary disease (COPD)		2
Insulin-dependent diabetes		2
Anaemia		3
End-stage renal disease		4

A risk-stratification algorithm to reduce superficial surgical site complications in primary hip and knee arthroplasty (Anatone et al, 2018)

Key points:

- The aim of this study was to develop a risk-stratification algorithm to reduce superficial surgical site complications in primary hip and knee arthroplasty
- The study found that ciNPT dressings are effective at reducing and normalising risks of superficial surgical site complications among high-risk primary arthroplasty patients
- The proposed risk-stratification algorithm may help identify those patients who benefit most from these dressings.

Risk factor	Points
BMI (kg/m^2) <18.5 18.5 – 29.9 30 – 34.9 35 – 39.9 >40	 1 0 1 2 3
Diabetes	2
Immunodeficiency	1.5
Active smoking	1
Non-ASA anticoagulation	1
Prior surgery	2

Risk calculators predict failures of knee and hip arthroplasties: Findings from a large health maintenance organization (Paxton et al, 2015)

Key points:

- The aim of this study was to develop a TKA and THA revision risk calculator using data from a large health-maintenance organisation's arthroplasty registry, and to determine the best set of predictors for a revision risk calculator
- The factors that can be best used to predict risk were calculated
- Surgeons can enter personalised patient data that can be used by surgeons to calculate individual patient risk, which can be used to guide clinical decision-making at the point of care.

Variables in the primary total knee replacement revision risk calculator		
Variable	Odds ratio (95% CI)	*p*-value
Age	0.96 (0.95–0.97)	<0.001
Sex	0.84 (0.75–0.95)	0.004
Diabetes	1.32 (1.17–1.48)	<0.001
Osteoarthritis	1.16 (0.84–1.62)	0.368
Post-traumatic arthritis	1.66 (1.07–2.56)	0.022
Osteonecrosis	2.54 (1.31–4.92)	0.006
Square-root BMI	1.05 (0.99–1.11)	0.140
Variables in the primary total hip replacement revision risk calculator		
Variable	Odds ratio (95% CI)	*p*-value
Age	0.98 (0.98–0.99)	<0.001
Sex	1.24 (1.05–1.46)	0.010
Osteoarthritis	0.85 (0.66–1.09)	0.190
Square-root BMI	1.07 (1.00–1.15)	0.066

MODELS FOCUSED ON SPINAL PROCEDURES

Web-based calculator predicts surgical site infection after thoracolumbar spine surgery (Lubelski et al, 2021)

Key points:

- The aim of this pilot study was to develop a model and simple web-based calculator to predict a patient's individualised risk of SSI after thoracolumbar spine surgery
- This tool has a predictive accuracy of 83%
- This tool has the potential to alert both patients and providers of an individual's SSI risk to improve informed consent, mitigate risk factors, and ultimately drive down rates of SSIs.

Risk factor	Odds ratio (95% CI)	p-value
Female sex	3.0 [1.3-7.0]	0.009
Greater body mass index	1.1 [1.1-1.1]	0.021
Active smoking	2.8 [1.1-7.1]	0.034
Diabetes	1.5 [0.7-3.3]	0.320
Worse ASA physical status	2.1 [1.1-4.5]	0.049
Greater surgical invasiveness	1.1 [1.1-1.1]	<0.001

Prediction tool for high risk of surgical site infection in spinal surgery (Namba et al, 2020)

Key points:

- This study aimed to develop a scoring system with reduced health care costs for detecting spinal surgery patients at high risk for SSI
- After narrowing down the variables by univariate analysis, multiple logistic analysis was performed for factors with *p* values <0.2, using SSI as a dependent variable; only factors that showed *p* values <.05 were included in the final models, and each factor was scored based on the β coefficient values obtained
- Applying these 5 independent predictive factors, infection incidence after spinal surgery can be predicted
- Stratification of risk employing this scoring system will facilitate the identification of patients most likely to benefit from complex, time-consuming and expensive infection prevention strategies, thereby possibly reducing health care costs.

Risk factor	Score
Emergency operation	2
Blood loss >400 mL	1
Presence of diabetes	1
Presence of skin disease	3
Preoperative total serum albumin value <3.2 g/dL	2

MODELS FOCUSED ON CARDIOTHORACIC PROCEDURES

Predicting cardiac surgical site infection: development and validation of the Barts Surgical Infection Risk tool (Magboo et al, 2020)

Key points:

- The objective of this study was to develop and validate a new risk tool (Barts Surgical Infection Risk (B-SIR)) to predict SSI risk after all types of adult cardiac surgery, and compare its predictive ability against existing (but procedure-specific) tools: Brompton-Harefield Infection Score (BHIS), Australian Clinical Risk Index (ACRI), National Nosocomial Infection Surveillance (NNIS)
- Thirty-four variables associated with SSI risk after cardiac surgery were collated from three local databases; independent predictors were identified using stepwise multivariable logistic regression; bootstrap resampling was conducted to validate the model; Hosmer-Lemeshow goodness-of-fit test was performed to assess calibration of scores
- B-SIR provides greater predictive power of SSI risk after cardiac surgery compared with existing tools for this population.

Risk factor	Score
Female gender	2
BMI >30 (kg/m^2) BMI >35 (kg/m^2)	1 3
Diabetes	1
Left ventricular ejection fraction <45%	1
Peripheral vascular disease	2
Operation type (coronary artery bypass graft)	4

An alternative scoring system to predict risk for surgical site infection complicating coronary artery bypass graft surgery (Friedman et al, 2007)

Key points:

- This study aimed to analyse the risk factors for SSI complicating CABG surgery and to create an alternative SSI risk score based on the results of multivariate analysis
- Six multivariate analysis models were created to examine either preoperative factors alone or preoperative factors combined with operative factors; all models revealed diabetes and BMI of 30 or greater as risk factors for SSI complicating CABG surgery
- A new preoperative scoring system was devised to predict sternal SSI, which assigned a point system
- The new scoring system performed better than the National Nosocomial Infections Surveillance System (NNIS) risk index at predicting SSI.

Risk factor	Score
Diabetes	1
BMI U30 - <35 kg/m^2	1
BMI U35 kg/m^2	2

Brompton Harefield Infection Score (BHIS): Development and validation of a stratification tool for predicting risk of surgical site infection after coronary artery bypass grafting (Raja et al, 2015)

Key points:
- This study was undertaken to develop a specific prognostic scoring system for the development of SSI that could risk stratify patients undergoing CABG
- Binary logistic regression analysis was used to identify independent predictors of SSI and develop a risk stratification system
- BHIS effectively predicts SSI risk and may help with risk stratification in relation to public reporting and reimbursement as well as targeted prevention strategies in patients undergoing CABG.

Risk factor	Score
Female gender	2
Diabetes or HbA1c >7.5%	1 3
BMI U35 kg/m^2	2
Left ventricular ejection fraction < 45%	1
Emergency surgery	2

Clinical predictors of major infections after cardiac surgery (Fowler et al, 2005)

Key points:
- The objective of this investigation was to create and validate a bedside scoring system to estimate patient risk for major infection (mediastinitis, thoracotomy or vein harvest site infection, or septicaemia) after CABG
- The resulting validated model can identify patients undergoing cardiac surgery who are at high risk for major infection
- These high-risk patients may be targeted for perioperative intervention strategies to reduce rates of major infection.

Risk factor	Pre-op Score	Combined Score
Age (for each year over 55)	1	1
BMI 30-40kg/m^2	4	3
BMI >40kg/m^2	9	8
Diabetes	3	3
Renal failure	4	4
Congestive heart failure	3	3
Peripheral vascular disease	2	2
Female gender	2	2
Chronic lung disease	2	3
Cardiogenic shock	6	N/A
Myocardial infarction	2	N/A
Concomitant surgery	4	N/A
Perfusion time 100 to 200 minutes	N/A	3
Perfusion time 200 to 300 minutes	N/A	7
Intra-aortic balloon pump	N/A	5

A new surgical site infection risk score: Infection risk index in cardiac surgery (Bustamante-Munguira et al, 2018)

Key points:

- The aim of this study was to analyse all SSI risk factors in both CABG and valve replacement patients in order to create a new SSI risk score for such individuals
- Data were collected and analysed on patients that underwent cardiac surgery
- Two preoperative variables were significantly associated with SSI
- The risk calculation aided clinical decision-making
- The authors concluded that personalisation of treatment for cardiac surgery patients is needed.

Risk factor	Score
BMI >30kg/m^2	1
Diabetes	1

OBSTETRIC AND GYNAECOLOGICAL RISK ASSESSMENT MODEL

Risk of complication at the time of laparoscopic hysterectomy: a prediction model built from the National Surgical Quality Improvement Program database (Pepin et al, 2020)

Key points:

- This study aimed to create a prediction model for complications at the time of laparoscopic hysterectomy for benign conditions
- The model is well calibrated for women at all levels of risk
- The laparoscopic hysterectomy complication predictor model is a tool for predicting complications in patients planning to undergo hysterectomy.

Risk factor	Increased risk for complications
History of laparotomy	2% increased odds of complication per year of life
BMI	0.2% increased odds of complication per each unit increase in BMI
Parity	7% increased odds of complication per delivery
Race	When compared with white women, black women had 34% increased odds and women of other races had 18% increased odds of complication
ASA 2	When compared to ASA 1 - 31% increased odds
ASA 3	When compared to ASA 1 - 62% increased odds
ASA 4	When compared to ASA 1 - 172% increased odds

VASCULAR RISK ASSESSMENT MODEL

Predictors of surgical site infection after hospital discharge in patients undergoing major vascular surgery (Wiseman et al, 2015)

Key points:

- The aims of this study were to explore the factors that lead to post-discharge SSI, investigates the differences between risk factors for in-hospital versus post-discharge SSI, and develop a scoring system to identify patients who might benefit from post-discharge monitoring of their wounds
- Risk scores were assigned to all significant variables in the model; summative risk scores were collapsed into quartile-based ordinal categories and defined as low, low/moderate, moderate/high, and high risk
- The post-discharge SSI rate was 2.1% for low-risk patients, 5.1% for low/moderate-risk patients, 7.8% for moderate/high-risk patients, and 14% for high-risk patients
- This scoring system can select a cohort of patients at high risk for SSI after discharge
- These patients can be targeted for transitional care efforts focused on early detection and treatment with the goal of reducing morbidity and preventing readmission secondary to SSI.

Risk factor	Score
Female gender	4
Obesity Overweight	9 3
Diabetes (insulin-dependent/non-insulin-dependent)	3/2
Smoking	2
Hypertension	2
Coronary artery disease	1
Critical limb ischemia	2
Chronic obstructive pulmonary disease (COPD)	1
Dyspnea with moderate exertion	2
Neurologic disease	1
Operative time >6 hours Operative time 4-6 hours	5 3
ASA class 4 or 5	2
Lower extremity revascularisation Aortoiliac procedure	12 9
Groin anastomosis	2

COLORECTAL RISK ASSESSMENT MODEL

Development and validation of a risk-stratification score for surgical site occurrence and surgical site infection after open ventral hernia repair (Berger et al, 2013)

Key points:

- This study aimed to develop a risk assessment tool for surgical site occurrence (SSO) and SSI and compare its performance against existing risk assessment tools in patients with open ventral hernia repair
- A retrospective study of patients undergoing open ventral hernia repair was conducted at a single institution; rates of SSO and SSI were determined by chart review
- Odds ratios were converted to a point system and summed to create the Ventral Hernia Risk Score (VHRS) for SSO and SSI, respectively.

Risk factor	SSO scores	SSI scores
Mesh implant	2	-
Concomitant hernia repair	2	2
Skin flaps created	2	2
ASA class U3	-	2
BMI U40 kg/m^2	-	3
Wound class 4	9	7

SURGICAL CANCER PATIENT RISK ASSESSMENT MODEL

Development and validation of a novel stratification tool for identifying cancer patients at increased risk of surgical site infection (Anaya et al, 2012)

Key points:

- The aim of this study was to identify cancer-specific predictors of postoperative SSI, and develop a risk-stratification prognostic tool and compare its performance with traditional measures
- A prospective cohort study of patients undergoing elective operations at a tertiary cancer centre was conducted; multivariate logistic regression analyses were performed to identify predictors of SSI and create a scoring system
- The Risk of Surgical Site Infection in Cancer (RSSIC) score was found to improve risk stratification of cancer patients and help to identify those that may benefit from more aggressive or novel preventive strategies.

Risk factor	Odds ratio (95% CI)	*p*-value
Preoperative chemotherapy	1.94 [1.2-3.3]	0.010
Operative time U2 h	1.75 [1.0-3.0]	0.040
Operative time U4 h	2.24 [1.2-4.1]	0.009
Incision site: groin	4.65 [1.7-12.8]	0.003
Incision site: head and neck	0.12 [0.0-1.0]	0.030
Wound type: Clean-contaminated	2.10 [1.2-3.6]	0.006

EMERGENCY SURGERY RISK ASSESSMENT MODEL

Risk factors for surgical site infections in patients undergoing emergency surgery: A single-centre experience (Papadopoulos et al, 2021)

Key points:

- The aim of this study was to determine the incidence of SSI in an emergency surgery cohort and identify risk factors for SSI
- Data from consecutive patients undergoing emergency surgery in a single institution were prospectively collected and analysed
- Identification of modifiable causative factors for SSI within an emergency surgery unit were found to be paramount, as they can critically impact postoperative outcomes.

Risk factor	Odds ratio (95% CI)	*p*-value
Severity	4.735 [2.5-9.0]	0.000
ASA class U2	8.963 [1.7-8.9]	0.001
Wound category	3.312 [1.3-8.7]	0.015
Remote infection presence	2.052 [1.0-4.3]	0.060
Duration U90 minutes	1.876 [1.2-3.0]	0.007
Transfusion of >2 red blood cell units	1.698 [1.9-3.0]	0.073
Diabetes	1.407 [0.9-2.3]	0.175
Preoperative length of stay >1 day	1.336 [0.9-2.0]	0.169
Obesity	1.289 [0.8-2.1]	0.302
Steroids	1.177 [0.8-2.5]	0.678
Antiplatelets	1.110 [0.6-2.1]	0.752
Anticoagulants	0.919 [0.4-2.1]	0.839
Coronary heart disease/chronic heart failure	0.902 [0.5-1.6]	0.721

NON-DISCIPLINE-SPECIFIC RISK ASSESSMENT MODELS

The Surgical Site Infection Risk Score (SSIRS): A model to predict the risk of surgical site infections (van Walraven and Musselman, 2013)

Key points:

- To capture factors particular to specific surgeries, the authors developed a surgical risk score specific to all surgeries having a common first 3 numbers of their Current Procedural Terminology (CPT) code
- Derivation and validation patients were similar for all demographics, past medical history, and surgical factors: overall SSI risk was 3.9%
- The SSI Risk Score (SSIRS) found that risk increased with patient factors, certain comorbidities, and operative characteristics
- In the validation population, the SSIRS had good discrimination and calibration
- SSIRS can be calculated using patient and surgery information to estimate individual risk of SSI for a broad range of surgery types.

Development of risk scoring tool to predict surgical site infections (Karellis et al, 2015)

Key points:

- The objective of this study was to develop a user-friendly tool quantifying SSI risk
- Of the 37 risk factors assessed, five were significantly associated with SSI development and were included in the SSI-risk scoring tool (see Table below)
- Overall, 2.8% of low-risk patients, 10.3% of moderate-risk patients and 15.8% of high-risk patients developed an SSI
- The JSS-SSI Risk Scoring Tool is a promising user-friendly tool for quantifying SSI risk; further validation of the tool will be subsequently conducted.

Risk factor	Score
Smoking	2
BMI (kg/m^2) M20 20.1 - 25 25.1 - 30 30.1 - 35 25.1 - 45 45	 -1 0 1 2 4 6
Peripheral vascular disease (score varies depending on wound type)	Clean 8 Clean/contaminated 1 Contaminated/dirty -2
Metastatic cancer	3
Steroids	3
Recent sepsis (score varies depending on wound type)	Clean 6 Clean/contaminated 4 Contaminated/dirty 1
Operating room location and urgency: Outpatient Inpatient, non-emergency Inpatient, emergency	 0 3 10
ASA class: 1 2 3+	 0 4 7
Operation duration >3.5 hours (score varies depending on wound type)	Clean 4 Clean/contaminated 5 Contaminated/dirty 3
Wound type: Clean Clean/contaminated Contaminated/dirty, infected	 0 6 12
General anaesthesia	3
Performance of more than one procedure*	2

* The tool also includes a range of scores for CPT3 scores by operating room location and urgency that, for space-saving reasons, are not shown in table above.

Risk factor	Score
Male gender	10
Inpatient status	50
Hypertension	13
Steroid use	13
Caregiver dependence for everyday activities prior to surgery	14

Surgical wound infection rates by wound class, operative procedure, and patient risk index (Culver et al, 1991)

Key points:
- A risk index was developed to predict a surgical patient's risk of acquiring an SSI
- The risk index score, ranging from 0 to 3, is based on the number of risk factors present (see Table below)
- The infection rates for patients with scores of 0, 1 , 2, and 3 were 1.5, 2.9, 6.8, and 13.0, respectively
- The risk index was found to be a significantly better predictor of infection risk than the traditional wound classification system and performs well across a broad range of operative procedures.

Risk factor	Risk index score based on how many risk factors are present, ranging from 0 to 3
ASA score 3+	
Wound classified as contaminated or dirty-infected	
Operation lasting over T hours (T depends on the operative procedure being performed)	

Development and validation of the Surgical Outcome Risk Tool (SORT) (Protopapa et al, 2014)

Key points:
- The aim of this study was to develop and validate a preoperative risk stratification tool to predict 30-day mortality after non-cardiac surgery in adults
- A model of 45 risk factors was refined on repeated regression analyses to develop a model comprising six variables (see Table below)
- The SORT allows rapid and simple data entry of six preoperative variables, and was found to provide a percentage mortality risk for individuals undergoing surgery.

Risk factor	Presence of risk factors used to calculate the patient's percentage mortality risk
ASA grade	
Urgency of surgery	
High-risk surgical specialty	
Surgical severity	
Cancer	
Age U65 years	

Wounds International