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Perioperative mortality as a meaningful indicator: Challenges and solutions for measurement, interpretation, and health system improvement

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ABSTRACT

Expanding global access to safe surgical and anaesthesia care is crucial to meet the health targets of the Sustainable Development Goals (SDGs). As global surgical volume increases, improving safety throughout the patient care pathway is a public health priority. At present, an estimated 4.2 million individuals die within 30 days of surgery each year, and many of these deaths are preventable. Important considerations for the collection and reporting of perioperative mortality data have been identified in the literature, but consensus has not been established on the best methodology for the quantification of excess surgical mortality at a hospital or health system level. In this narrative review, we address challenges in the use of perioperative mortality rates (POMR) for improving patient safety. First, we discuss controversies in the use of POMR as a health system indicator and suggest advantages for using a "basket" of procedure-specific mortality rates as an adjunct to gross POMR. We offer then solutions to challenges in the collection and reporting of POMR data, and propose interventions for improving care in the preoperative, operative, and postoperative periods. Finally, we discuss how health systems leaders and frontline clinicians can integrate surgical safety into both national health plans and patient care pathways to drive a sustainable safety revolution in perioperative care.

Background

Surgical providers perform 313 million procedures worldwide each year, saving lives and improving the welfare of millions of people [1]. The mortality risk for an individual procedure is usually low, and most patients survive to benefit from surgery. However, some patients experience complications and a small proportion die during the perioperative period. Scaled globally, 4.2 million deaths occur within 30 days of surgery each year, placing perioperative mortality as the third most common category of death after ischaemic heart disease and stroke [2]. While many patients die from their presenting illness despite surgery rather than because of it, the magnitude of excess surgical mortality mandates its management as a high-priority public health problem [3].

A fraction of the world's population has access to safe surgical and anaesthesia care; for 4.8 billion people this lifesaving treatment modality is unavailable, unaffordable, or otherwise inaccessible [4]. A dual focus on expanding access while establishing and improving infrastructure to rescue patients who suffer complications is necessary for realising the full potential of surgery. The Perioperative Mortality Rate (POMR) is a health system-level indicator, which has been proposed by several groups to measure and track the safety of surgery and anaesthesia [5–7]. As defined by The Lancet Commission on Global Surgery, it is calculated as the total national number of inpatient deaths following surgery divided by the annual surgical volume [8]. The indicator is intended to demonstrate the facilities, material resources, expertise, and health systems working in concert to deliver the best possible perioperative outcomes. The World Health Organisation has included POMR among its list of 100 core global health indicators [9].

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This narrative review aim to define the challenges that face health practitioners wishing to meaningfully use POMR to improve the quality and safety of surgical care. Further, we propose solutions to these challenges to support global data collection and the adoption of POMR for quality improvement, research, and advocacy.

Gross national POMR: Too blunt a tool

The gross national POMR is conceptually simple, and as such, has an important role in public accountability. It is designed to be considered alongside surgical volume (number of operative procedures per 100 000 population per year) to ensure that health systems are delivering surgery at appropriate quantity and quality [8]. Surgery is a difficult concept to define and there is little consensus regarding which procedures should be considered as surgery. Attempting to define surgery according to who performs it, where, or under what type of anaesthesia invariably results in problematic exceptions. It is nonetheless important, since the definition of surgery used can significantly alter the overall POMR estimate [10]. Note that by definition, POMR does not count individuals who die from surgical disease before the patient enters the operating theatre. To include this "preoperative" mortality would require the use of a diagnosis-based indicator, introducing additional challenges in enumerating the denominator.

Although low POMR may be interpreted as representing optimal care and high POMR as indicating the need for improvement, the relationship between POMR and quality is more complex. How the indicator is defined, the cases included in its denominator, and even how the data are collected can influence reported POMR [11]. The gross national POMR is too blunt an instrument to accurately describe system performance or point towards mechanisms for improvement.

A more detailed measurement tool could better facilitate improvement, enabling institutional and national comparisons. To better understand what such a tool should accomplish, we define five categories of outcomes following surgery (Fig. 1):

- **Natural survival:** an individual survives surgery, but would have also done so even without surgical intervention. Examples: cataract surgery, simple inguinal hernia repair, knee arthroplasty.
- **Surgery-attributable survival:** an individual survives but would have died within days if not for surgical intervention. Examples: surgery for ruptured abdominal aortic aneurysm, Hartmann's procedure for perforated diverticulitis with generalised peritonitis.
- **Surgery-attributable mortality:** an individual would have survived without surgery but dies due to surgical or anaesthetic complications. Example: on-table anaphylaxis during simple inguinal hernia repair.
- **Disease-attributable avertable mortality**: an individual dies after surgery performed for a life-threatening condition but could have survived in an ideal health system. The cause of death may relate to either surgical complications or underlying pathology. Examples: death as a result of postoperative pneumonia (surgical complication) or a paraneoplastic syndrome (underlying pathology).
- **Unavertable mortality:** an individual with lethal underlying disease whose prognosis is very unlikely to be improved by surgery; they would die postoperatively within days or weeks even in the most effective health system with modern resuscitative technologies. Example: trauma surgery for a patient with catastrophic head injury.

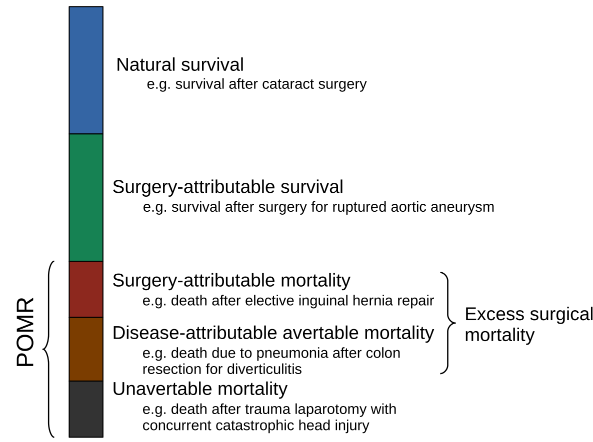

Fig. 1. Classification of perioperative survival outcomes.
To fully explore the relationship between surgery and mortality, a clear classification of outcomes is required. The goal of studying POMR is to reduce both surgery-attributable mortality and disease-attributable avertable mortality to maximise survival in the perioperative period. Unavertable mortality is defined as deaths that are not preventable even in the best-performing health system. As technology and medical science develop, this may continue to decline. Note that bar sizes in this graphic are arbitrary.

Surgical systems work to maximise surgery-attributable survival and minimise surgery-attributable mortality and disease-attributable avertable mortality. The sum of the latter two is *excess surgical mortality*, otherwise defined as the difference between total perioperative mortality and unavertable mortality. Quantification of excess surgical mortality can motivate investment in the physical infrastructure, materials, and human resources required to improve surgical safety. The first three challenges we discuss below address the selection of more nuanced POMR indicators, how data can be collected and tracked over time, and how these data should be reported.

Challenge 1: Selecting procedures to track

To determine excess surgical mortality in one setting, both total mortality and mortality in the best-performing comparator (BPC) are required. Depending on the level of the analysis, the BPC could be the best-performing hospital in a city, district in a country, country in a region, or country in the world. Case mix, which we define as the makeup of the surgical population by diagnoses and procedures, must be considered in this calculation. If it were identical between settings, then excess surgical mortality would simply be the difference between total gross mortality and that in the BPC. However, case mix differs significantly between countries, between rural and urban environments, and between individual hospitals, rendering such simple arithmetic meaningless [12–14]. Strategies to account for confounding by case mix could include adjustment via regression modelling and stratification by procedure or diagnosis [15]. No standardised methodology exists to adjust gross POMR for case mix via regression modelling.

Therefore, we propose that to robustly report meaningful POMR a "basket" of pre-selected procedures should be established. Routine data collection can then be focused on this subset of procedures, reducing the overall burden of data collection, while harmonising the data collected across different settings [16]. Criteria for the selection of procedures for inclusion in the basket have previously been proposed [11], but these remains problematic due to conflicting considerations (Table 1). A Delphi process is currently ongoing to establish an initial basket, but this will require validation and refinement prior to its widespread adoption. A selection of procedures for which perioperative mortality data

Table 1
Criteria for the selection of representative procedures.

Criteria	Rationale	Challenge
The procedure should be frequently performed across all settings globally.	(1) If a procedure is performed only in specialised centres, outcomes data will be meaningless to district hospitals, which is where most surgeries are delivered globally [8]. (2) If a procedure is performed rarely, the POMR denominator at any centre will be small, leading to unstable estimates with wide confidence intervals.	Focusing solely on procedures common across the world may result in missed key procedures frequently seen in one setting but not another; for example rectal cancer surgery in high income settings and surgery for perforated typhoid in low income settings [18,19].
The mortality risk of the procedure should be significant.	If mortality is low, reliably estimating POMR will require many cases, especially if adjustment for multiple patient-level risk factors is required.	Procedures with low baseline mortality risk may in fact demonstrate significant variation in POMR across settings. For example, caesarean section POMR in Africa is 0.5%, which is fifty times higher than in Europe [20].
Procedures should represent the burden of surgical disease across the population.	To ensure that any service improvements aimed at improving POMR are equitable, data should be captured that is representative across the lifespan and gender.	Procedures specific to one population with a high mortality risk (e.g. repair of gastroschisis in neonates) may be performed rarely.
Procedures should be selected for which there is already a robust body of risk adjustment literature.	Knowledge of key mortality risk factors for individual procedures will enable efficient data collection capturing the variables necessary for robust risk adjustment.	If risk adjustment literature is based solely in high-income countries, models may be poorly calibrated to other settings. Risk adjustment strategies will need to be refined for fair global comparisons.

have been published from various settings is presented in Table 2 [11–13,17].

Once a basket is successfully established, POMR for each constituent procedure can be adjusted for patient-level risk factors via regression modelling. This strategy will allow clinicians to benchmark procedure-specific performance in one context against the BPC fairly.

Challenge 2: Collecting data

The collection of healthcare data requires monetary investment in human resources and technology. The increasing digitisation of health systems greatly facilitates monitoring and evaluation [21], but its progress is not universal. Many systems, even in high-income countries, still use paper documentation. Further, the validity of administrative data from digital systems is variable and dependent on consistent, accurate imputation. In most contexts, the routine collection of perioperative data will be an additional demand, felt most heavily in the lowest income countries with a high burden of disease [22]. A minimum dataset has been proposed to allow for the accurate reporting of elegantly risk-adjusted POMR with a low collection cost [23]; the minimum dataset required will likely vary by procedure.

To fill the data gap, a major centre in Uganda has established a surgical registry [24]. This registry allows for the accurate

Table 2
Reported surgical volume and perioperative mortality for selected procedures in Australia, Europe, Africa, and across Low- and Middle-Income Countries.

Specialty	Procedure	Proportion of surgical volume in Victoria, Australia* (%)	Inpatient mortality in Victoria, Australia (%)	Proportion of surgical volume in ASOS (%)	Inpatient mortality in ASOS (%)	Proportion of surgical volume in EuSOS (%)	Inpatient mortality in EuSOS (%)	SR: Number of studies reporting POMR in LMICs 2009-	Inverse-variance-aggregated POMR SR 2009-2014
Orthopedic				15.54	1.53	26.24	3.83		
	Hip replacement and revision	1.96	1.08						
	Hip replacement and revision (for injury)	0.42	4.26					5	7.73
Breast surgery				2.01	0.87	3.22	2.87		
	Major procedure for breast conditions	1.24	0.02						
	Minor procedure for breast conditions	0.61	0.01						
Obstetrics				33.28	0.53				
	Caesarean delivery	4.43	0.01					55	0.05
	Emergency peripartum hysterectomy							39	7.81
Gynaecology				11.45	0.54	8.53	2.90		
	Uterine and adnexal procedure for malignancy	0.21	0.37						
	Hysterectomy for non-malignancy	1.10	0.01						
	Hysterectomy							5	0.98
Upper gastrointestinal tract				2.64	9.63	4.79	6.96		
	Gastric malignancy							18	3.72
Lower gastrointestinal tract				8.25	4.89	10.68	5.71		
	Major small and large bowel procedures	0.80	3.36						
	Colon resection, excluding volvulus							27	2.83
	Appendectomy	1.18	0.03					23	0.01
	Surgery for non-typhoid hollow viscus perforation							22	11.85
	Rectal resection	0.33	1.68					9	0.07
	Surgery for typhoid-related hollow viscus perforation							9	20.09
Hepatobiliary				1.51	2.33	4.83	5.03		
	Pancreas, liver, and shunt procedures	0.17	1.01						
	Major biliary tract procedures	0.11	5.23						
	Hepatic resection							20	1.04
	Cholecystectomy							15	0.00
	Whipple procedure							10	2.94
Urology				4.92	2.32	11.48	2.86		
	Major male pelvic procedures	0.32	0.02						
	Trans-urethral resection of the prostate	1.05	0.15						
	Kidney, ureter, and major bladder procedures for neoplasm	0.24	0.79						
	Prostatectomy							5	0.40
Vascular				2.08	6.75	5.11	5.89		
	Major reconstructive vascular procedures without CPB pump	0.31	2.71						
	Vascular procedures except major reconstruction without CPB pump	0.90	0.79						
	Thoracic aortic disease							8	9.50
	Abdominal aortic aneurysm							7	10.90
	Peripheral arterial bypass							4	4.24
	Vascular procedures not otherwise specified							6	6.43
Head and neck				3.98	2.87	12.12	3.09		
	Thyroid procedures	0.51	0.08						
	Surgical management of goitre							4	0.00
Cardiac surgery				0.51	10.34				
	Coronary artery bypass graft	0.38	0.77					49	4.38
	Cardiac valve procedures	0.33	1.72					35	4.17
	Cardiac surgery, not otherwise specified							31	4.96
	Pediatric cardiac procedures							19	6.76
Thoracic (lung and other)				1.14	6.15				
	Major chest procedures	0.34	3.94						
	Pulmonary resection, excluding resection for tuberculosis							23	1.30
Thoracic (gut)				0.20	8.70				
	Surgery for esophageal malignancy							13	5.40
Neurosurgery				2.22	8.30				
	Cranial procedures	0.55	4.70						
	Resection of intracranial mass							19	1.29
	Surgical management of hydrocephalus							6	1.60
	Neurosurgical procedure, not otherwise specified							5	5.78
Neonatal and pediatric									
	Neonate with significant OR procedure	0.05	4.59						
	Surgical management of intussusception							8	4.80
	Surgical management of gastroschisis							4	29.68
Other				4.87	1.98	7.44	3.81		
	Hernia procedures	3.09	0.05						
	Inguinal hernia repair							17	0.38

European Surgical Outcomes Study (EuSOS) or African Surgical Outcomes Study (ASOS)
Population-level observational study in Victoria, Australia (Fehlberg et al, 2019)
Systematic review (SR) of perioperative mortality in low- and middle-income countries 2009-2014 (Ng-Kamstra et al 2018)
Fehlberg et al and Ng-Kamstra et al

<0.1%
0.1 – 0.99%
0.1 – 1.99%
2.00 – 4.99%
≥5.00%

*A retrospective population-based study of all surgical procedures performed in the Australian state of Victoria between January 2014 and December 2016. **A systematic review (SR) of all studies reporting perioperative mortality rates in low- and middle-income countries between January 2009 and December 2014. ASOS- African Surgical Outcomes Study. EuSOS- European Surgical Outcomes Study. Proportional surgical volume is calculated as number of patients undergiong a specific procedure divided by total surgical denominator in each study.

determination of surgical volume at the centre and the reporting of procedure-specific outcomes. The registry thoroughly enumerates the surgical denominator, accurately classifies surgical procedures, uses consistently defined and imputed variables, and provides complete follow-up on included patients [25].

Not all centres will have the surgical volume or financial resources required to hire data specialists to collect, enter, and validate data. It may be more feasible and sustainable for these hospitals to participate in short data collection exercises. The GlobalSurg Collaborative adapted the snapshot study methodology to engage and empower an international network of clinicians and researchers to lead and contribute to prospective surgical outcomes studies [26]. The first GlobalSurg study aimed to determine the outcomes of emergency abdominal surgery across settings [27]. Investigators across 357 centres collected patient outcomes during two-week data inclusion windows. Data captured from 10 745 patients across 58 countries were included in the final analysis. This study provided invaluable insights into system-level variables that could be leveraged to reduce mortality. The generalisability of GlobalSurg's country-level outcomes data is unknown, given that sites contributed data on a voluntary basis, potentially leading to over-representation of larger, university-affiliated centres, and under-representation of district hospitals. The African Surgical Outcomes Study (ASOS) employed similar methodology, with a focus on engaging surgeons across Africa. While they succeeded in collecting data across 247 hospitals in 25 African countries [12], many barriers to participation in the study were identified relating to resource limitations, again suggesting that the most under-resourced centres may not have been able to contribute [28].

Many low and lower-middle income countries have low surgical volume [16]. This makes it practically difficult to collect sufficient data to produce meaningful nationally representative *procedure-specific* POMRs. Given these challenges, modelling may be an appropriate stop-gap measure until reliable primary data is more readily available. There are now several large international studies (ASOS, EuSOS, and ISOS) that report perioperative mortality using similar methodology [12,13,29]. These data can be used together with published country-level development, economic, and health metrics (e.g. national density of surgical, anaesthetic, and obstetric (SAO) providers) to develop granular national POMR estimates. POMR estimates may motivate policy makers to invest in systems to sustainably collect real-world POMR data.

A final consideration is the follow-up time-window for POMR. Inpatient measurement of POMR up to 30-day postoperative has been widely adopted as a pragmatic approach to ensure accurate data collection [5,6,8]. However, in high-resource settings, improvements in postoperative care have prolonged the interval between operation and postoperative death. In these high resource settings, the 90-day POMR is increasingly more discriminative and meaningful than either 30-day or inpatient POMRs [30,31]. While capture of 90-day POMR is not feasible in most low- or middle-income countrit (LMIC) settings, increasing digitisation and uptake or mobile phone technology may make this a realistic target in the future. Recognising current limitations in collecting POMR data, a set of pragmatic recommendations are summarised in Table 3.

Challenge 3: Communicating POMR data

Reporting surgical mortality data has high stakes [32,33]. The purpose of this indicator is to strengthen health systems and to support clinicians in improving perioperative safety, but the data can be used to shame and punish surgeons for outcomes that may be out of their control.

Public reporting of some surgeon-specific outcomes began in New York after legal challenges [32], and other health systems have since embraced this as a key strategy to drive quality improvement [34]. There is evidence that publicly reporting surgeon-specific outcomes may be associated with significant reductions in POMR [34]. Conversely, the experience of the US-based National Surgical Quality Improvement Programme suggests that non-public reporting of outcomes to hospitals may be insufficient to drive change [35].

Critics fear that publicly exposing surgeons' outcomes may be a deterrent to surgeons taking on complex, high-risk patients, thereby decreasing access to those patients who need surgery the most. Such deleterious effects have not been detected in health systems, which have implemented surgeon-specific outcome reporting [32,34]. Similarly trainee involvement in surgery has not been adversely effected by POMR reporting in the UK [36]. Nonetheless, committing to publishing appropriately risk-adjusted rather than raw POMRs is likely to be met with more support from the surgical community, particularly those who work with high-risk populations.

A further challenge with surgeon-specific outcome reporting is the relatively low surgical volume of most surgeons. This can make identification of poor performance problematic [37]. Reporting POMR at institutional or regional levels is more likely to allow meaningful benchmarking and identification of outliers [32]. While surgeon-specific POMRs are a valuable metric for internal review, reporting of POMRs at the highest relevant level can ensure a focus on system improvement rather than fuelling a damaging blame culture [38]. In jurisdictions where volume remains too low for stable estimates, reporting rules could prevent the public release of data until accumulated data meets a pre-established denominator threshold.

Finally, regardless of the methodology used to collect POMR statistics, it is critical that this methodology is clearly described to enable appropriate interpretation. This should include a description of the procedures and patients included (e.g. comorbidities and risk factors), the study design, the follow-up timeframe (inpatient, 30-day, or longer), loss to follow-up, and risk-adjustment methodology, if applicable [11].

Table 3
Pragmatic recommendations for the collection of POMR data.

Domain	Ideal	Pragmatic
Procedures for which POMR is tracked	All patients undergoing surgery.	Key procedures included in "surgical basket".
Endpoint/follow-up	Mortality within 90 days of surgery.	Inpatient mortality within 30 days of surgery.
Data collection	Automatic reporting via electronic health records.	Prospective data collection in short data capture windows.
POMR reporting	National data collated by ministries of health and included in World Development Indicators dataset.	Publication of hospital, regional, and national-level data in peer-reviewed journals.
Data modelling	Not required.	Best available real-world data used to model estimates for countries for which there is currently limited data.

Challenge 4: Identifying the root causes of excess surgical mortality

The wide global variation in POMR indicates that there are hundreds of thousands if not millions of postoperative deaths each year that are potentially avoidable [12,27,29]. Well-resourced universal health systems have demonstrated that despite low baseline POMR a concerted focus on quality improvement can result in substantial cumulative improvements. For example, over a 20-year period, the national health systems in both England and Scotland achieved overall reductions in POMR of 37–39% [39,40].

Identifying specific targets for improvement can be challenging since individual postoperative deaths are invariably multifactorial, complex, and unique. Although there is little high grade evidence to support the effectiveness of national confidential enquiries, by systematically reviewing deaths in detail across multiple institutions, key themes can be identified and recommendations made [41]. For example, following recommendations from the original National Confidential Enquiry into Patient Outcome and Death (NCEPOD) report, hospitals in the United Kingdom introduced a standardised classification to rate surgical urgency, established dedicated theatres, and reviewed the need for supervision of out of hours surgery by senior surgeons [42].

Dividing the patient's care into preoperative, intraoperative, and postoperative time periods can reveal opportunities to reduce perioperative mortality, which we explore in the next three challenges. Factors to consider and possible reduction measures are summarised in Fig. 2.

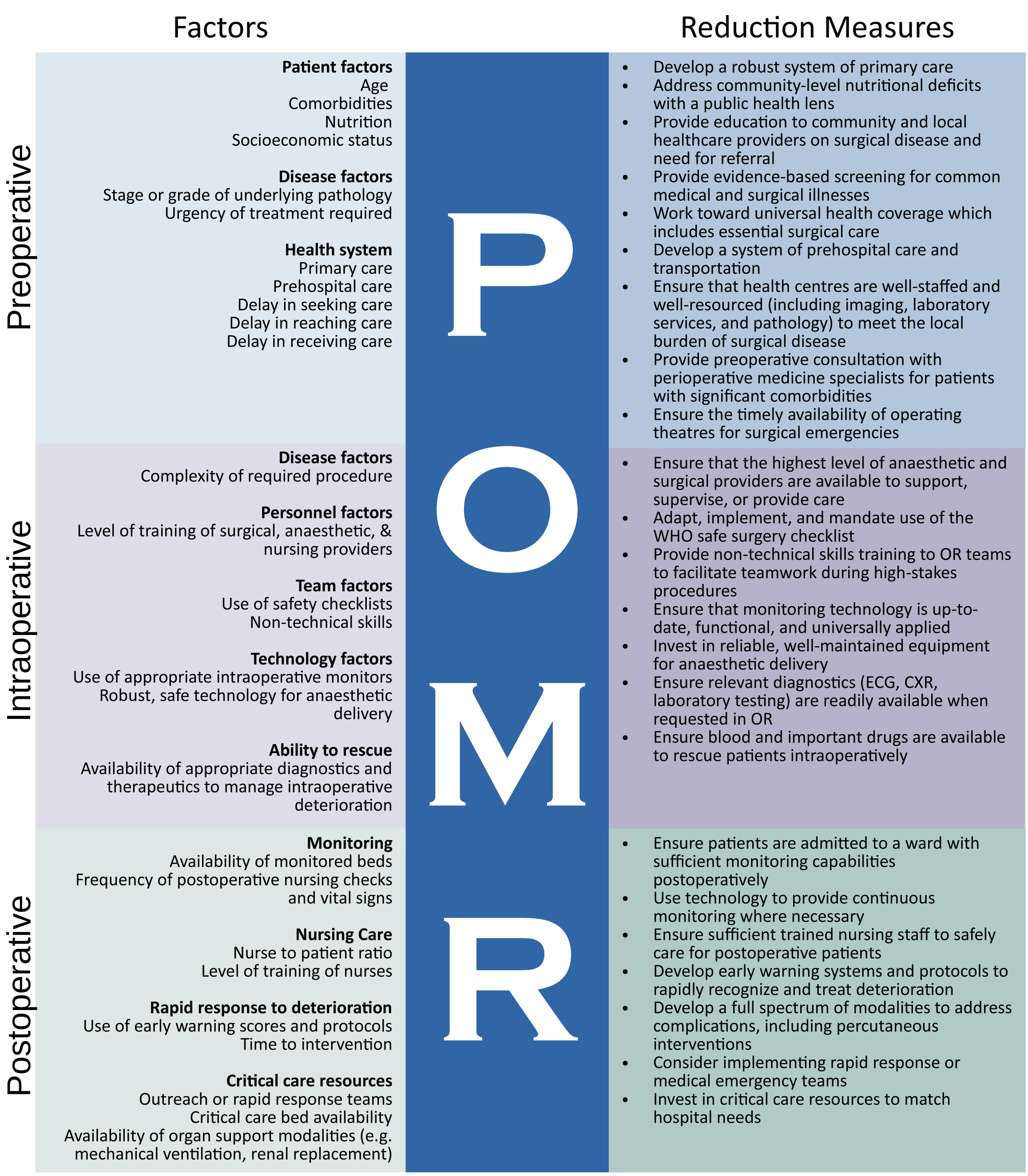

Fig. 2. Factors influencing perioperative mortality rates and reduction measures to consider.

Challenge 5: Improving preoperative care

The patient's condition at admission can strongly influence the outcome of surgery. Preoperative factors may significantly contribute to the difference in POMR between high-, middle-, and low-income countries [27]. Surgical care is delivered within the context of broader health systems. Universal access to primary care and essential medicines ensures that patients' comorbidities are appropriately managed and this may improve surgical outcomes downstream [43]. Similarly, perioperative medicine specialists such as internal medicine or anaesthesia can help to optimise patients' comorbidities in the preoperative setting, mitigating risk by, for example, investigating and managing pre-existing coronary disease [44].

Malnutrition is independently associated with surgical complications and mortality [45,46]. In some communities this may be a population-level problem best addressed through public health interventions, but even in well-fed societies disease-related malnutrition is common. Clinical intervention with enteral or parenteral feeding may be appropriate for some patients in order to address preoperative malnutrition [47].

Although the severity of a patient's illness is often thought to be non-modifiable, severity is often related to delays to care [48]. The Three Delays Framework is a useful model for understanding and reducing delay [8]. Reasons for delay in seeking care ("first delay") vary across communities and patients with different pathologies. Common barriers relating to health seeking behaviours and poverty can at least partly be addressed by ensuring that universal health coverage includes essential surgical care. Initiatives to engage and train traditional and religious healers can also improve access to conventional healthcare; for example, training birth attendants to recognise congenital anomalies may lead to earlier diagnosis and treatment [49]. Delay in reaching care ("second delay") may occur in communities that either lack of means of transportation, or are far from health facilities [50]. Additional delays may occur if patients present to health facilities that are unable to provide the complexity of care that they require. These delays can be reduced by the establishment of emergency medical transportation services and well-resourced hospitals capable of delivering essential surgery that are linked through referral networks accessible to rural populations. Once at an appropriate health facility, there may be a delay in patients receiving definitive intervention ("third delay"). Factors such as a lack of clinical staff, unavailability of diagnostics, and lack of theatre time or equipment may contribute to delays. Growing the SAO and allied health workforce and ensuring that they have the materials and well-maintained equipment they need could minimise in-hospital delay [8].

Finally, while an operative approach can be lifesaving, in some patient contexts, non-operative management is best suited to reach patient goals. Patient selection for surgery is critical to maximise benefit and minimise harm, and it must be individualised. Simple risk stratifications tools to calculate and communicate the risks of surgery have been developed in both high-income and low- and middle-income countries [51,52], but they are inconsistently applied in routine practice.

Challenge 6: Improving intraoperative care

The patient's diagnosis, the magnitude of the surgery required to address it, and the urgency of the presentation are major determinants of POMR [13,53,54]. Even for high-risk emergency surgery, however, risk can be mitigated by implementing safety processes, using appropriate intraoperative monitoring, ensuring skilled staffing, and making relevant technologies, resources, and medications available to rescue patients in the event of intraoperative deterioration.

The WHO surgical safety checklist has transformed intraoperative safety. Since its introduction, it has been implemented in operating theatres around the world, though with varying fidelity [27,55]. In addition to steps to ensure that the right procedure is performed on the right patient, technology checks are mandated, patient allergies are reviewed, and the patient's airway is assessed [56]. The surgical and anaesthesia team make plans to address anticipated blood loss, review indications for antibiotic prophylaxis, and invite team members to voice concerns. The checklist can be modified to include items such as thromboprophylaxis and any locally important or specialty-specific concerns. Use of the checklist is associated with reduced perioperative mortality in some studies [27], but others have not demonstrated this [57,58].

Beyond basic anaesthesia monitoring including pulse oximetry, ECG, and non-invasive blood pressure monitoring [59], other devices such as arterial and central venous catheters can be used for high-risk patients, although the mortality benefit of this is uncertain. The use and benefit of advanced physiologic monitoring go beyond the scope of this review and are likely to depend on the training and preferences of the anaesthetic provider.

The level of training of the surgical and anaesthesia providers may influence outcomes. While task-shifting studies have shown similar mortality rates between non-physician clinicians and trained surgeons in sub-Saharan Africa [60], the high-income country literature has demonstrated a relationship between volume and outcome even amongst fully trained surgeons [61,62]. The nature and magnitude of the relationship between level of training, volume, and outcome are likely to vary between procedures and contexts. To reduce mortality rates, the available provider with the highest level of training and volume in any context should be available to perform, assist, or supervise the conduct of anaesthesia or surgery.

Finally, if the patient's condition deteriorates during an operation, the anaesthetist and surgeon should have the assistance and resources required to diagnose and treat the problem quickly. This may include tests such as ECG, echocardiogram, X-ray, and laboratory testing, and treatments such as blood products, vasoactive medications, inotropes, and bronchodilators. Non-technical skills training can help all team members work collectively to rescue the patient using a shared mental model of the problem, closed-loop communication, and judicious use of scarce human resources [63,64].

Challenge 7: Improving postoperative care

Relatively few patients die during an operation, with the majority dying later following a complication [65]. Postoperatively, most patients are admitted to a general ward, where care is highly variable. Standardising this care may reduce complication and mortality rates. While the optimal frequency of nursing care and the measurement of vital signs will vary by diagnosis, procedure, and patient stability, standardised protocols for how to use this information have emerged. Aggregate-weighted scoring systems that summarise data from derangement in multiple vital signs have been developed to create early warning scores (EWS) [66]. Protocolised activation of nurse-led, physician-supported teams based on changes in EWS may improve hospital survival, reduce cardiac arrest calls, and unplanned admission to ICU [66], though these effects have not been consistently demonstrated in the literature [67]. Further, data from Sri Lanka and Malawi have shown disappointing performance of existing EWS in the prediction of deterioration and hospital mortality in these settings [68,69]. Further work is required to develop systems of postoperative surveillance that meet the needs of LMIC hospitals. Disruptive technologies such as wearable devices that continuously monitor vital signs and use artificial intelligence to predict deterioration may prove useful in hospitals with low nurse-to-patient ratios [70].

Protocols and devices, however, are no replacement for the expansion of a skilled nursing workforce. High-quality nursing care is essential for promoting postoperative recovery, preventing complications, and the detection and management of deterioration. Nurse-to-patient ratios are often far lower in LMICs than in HICs [71]. In the UK, lower RN staffing was found to be associated with a higher risk of in-hospital death in general medical and surgical wards [72]. In a perioperative nursing study conducted in 300 centres across 9 countries, an increase in a nurse's workload by one patient resulted in a 7% increase in mortality within 30 days of admission; this mortality risk was mediated by an increase in medically necessary care that was missed due to a lack of available time [73]. Training, hiring, and supporting nurses in providing optimal perioperative care should be a priority for reducing POMR.

When complications or deterioration are detected, appropriate interventions to rescue the patient may include medical therapy (for example, antibiotic or fluid administration), a non-operative procedure, reoperation, or admission to the ICU for organ support. "Failure to rescue" is defined as death following a postoperative complication; this is a valuable marker of a hospital's ability to provide ongoing safe care [74]. Intuitively, critical care resources are important for rescuing patients. One observational study of elective surgery, however, failed to show a decrease in POMR with greater ICU availability and use, but the potential for residual confounding limits the conclusiveness of this finding [75]. There may be a minimum availability of critical care resources to prevent death, above which further expansion is of limited benefit. Beyond the capacity for ICU-based organ support, timely response to deterioration while physiologic derangement is reversible with simple ward-based interventions is critical [67].

To reduce the global burden of perioperative mortality while expanding access to surgical care, these challenges will need to be acknowledged and addressed comprehensively. The final challenge we discuss is the engagement of multiple stakeholders to catalyse and sustain reductions in POMR globally.

Challenge 8: Implementing and sustaining system-level change

Actors at all levels of the healthcare system can work to improve the quality of care delivered throughout the patient pathway. Without resources and incentivisation from hospital, regional, and national leaders, however, improvements are likely to be poorly sustained, sporadic, and inequitably distributed [76].

The Lancet Commission on Global Surgery introduced the concept of National Surgical, Obstetric, and Anaesthesia Plans (NSOAPs) in 2015 [8]. Several countries have since developed such plans, addressing health infrastructure, workforce, financing, information management, and service delivery needs to achieve universal access to safe, affordable surgical and anaesthesia care when needed [77,78]. Embedding quality and safety into NSOAPs with earmarked resources to address identified safety needs can promote change at a national level. The NSOAP movement continues to expand; priorities for developing the movement include robust evaluation of the results of implementation in countries pioneering the NSOAP approach [79].

Even with governmental prioritisation of surgical safety, the specific interventions that are likely to lead to the greatest change in perioperative mortality have yet to be determined, and implementation on a large scale remains challenging. The concept of "care pathways" for surgical patients is an attractive option, providing standardised approaches to common clinical problems. A basic care pathway for emergency laparotomy resulted in a decrease in perioperative mortality from 15.6 to 9.6% in four UK hospitals in a study using a before-and-after cohort design [80]. More recently, a comprehensive, 37-item care pathway for emergency abdominal surgery patients implemented in 93 hospitals in the UK proved to be too complex to implement with high fidelity in the absence of a major financial and human resource investment [81]. These studies illustrate the tension between comprehensiveness and elegance: while comprehensive pathways may capitalise on the marginal benefit of all potentially beneficial interventions and so may demonstrate high efficacy, elegant pathways leverage higher fidelity in implementing the highest yield interventions leading to better real-world effectiveness. This duality should be carefully considered in any intervention planned for wide implementation in resource-limited contexts. Even streamlined interventions, however, require resources to implement and maintain. Systems looking to make sustainable improvements can consider investing in clinicians with an interest in quality improvement by providing the financial and human resources they need to create lasting change.

Conclusion

When broken down into problems of measurement, reporting, and evidence-based clinical care, the large and seemingly intractable problem of global perioperative mortality becomes manageable. The first step in this movement is to create, measure, and track POMR indicators that are believed by clinicians and policymakers. Evidence-based action to reduce POMR should then be coupled to evaluation to create a virtuous cycle of investment of time and resources into surgical safety. While governmental engagement is important, progress will depend on frontline clinicians. Locally-driven quality improvement initiatives supported by financial and clinical resources can drive a global safety revolution in perioperative care.

Disclosure of interest

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CRediT authorship contribution statement

JNK, DN, IL, and AB conceived the manuscript. JNK, DN, and IL developed figures and tables. JNK drafted the manuscript. JNK, DN, IL, RS, and AB contributed content, critically reviewed the manuscript, and approve of the final version.

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