Global burden of postoperative death

The *Lancet* Commission on Global Surgery[1] identified that 313 million surgical procedures are performed worldwide each year. Little is known about the quality of surgery globally because robust reports of postoperative death rates are available for only 29 countries.[2] The rate of postoperative deaths is a measure of the success of surgical care systems, and improving this metric is a global priority.

We aimed to estimate, on the basis of surgical volume, case mix, and postoperative death rates adjusted for country-income level, how many people around the world die within 30 days of surgery. England's combined Hospital Episode Statistics and Office of National Statistics (HES-ONS) dataset is one of the world's most comprehensive procedure-specific resources on mortality, reporting national coverage from a universal health-care system. We used the HES-ONS dataset as the baseline for our estimations for high-income settings and adjusted case-mix and mortality in HES-ONS to estimate total postoperative deaths in low-income and middle-income countries (LMICs). We estimated probable additional postoperative deaths if surgical volume were expanded to address the annual unmet need for 143 million surgical procedures in LMICs (appendix).[3]

Our analysis suggests that at least 4·2 million people worldwide die within 30 days of surgery each year, and half of these deaths occur in LMICs. This number of postoperative deaths accounts for 7·7% of all deaths globally,[4] making it the third greatest contributor to deaths, after ischaemic heart disease and stroke (figure). More people die within 30 days of surgery annually than from all causes related to HIV, malaria, and tuberculosis combined (2·97 million deaths).[4] We project that an expansion of surgical services to address unmet need would increase total global deaths to 6·1 million annually, of which 1·9 million deaths would be in LMICs.

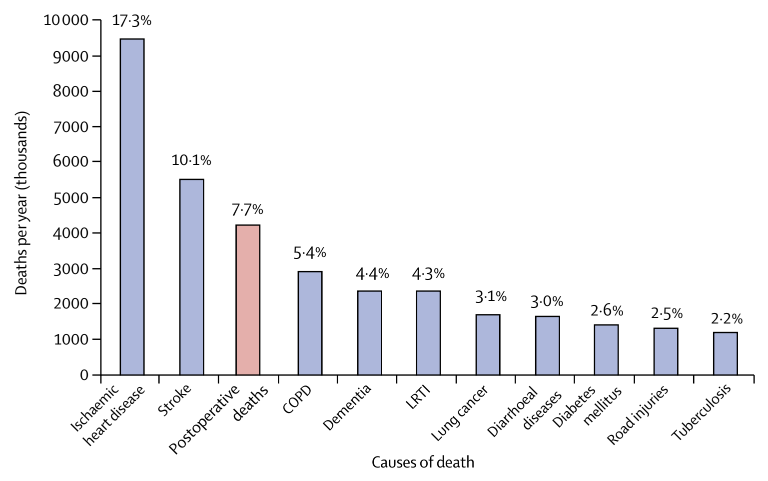

***Figure:* Top ten global causes of death, 2016**
Percentages are the proportion of total global deaths attributable to each cause. Data, except those on postoperative deaths, are from the Global Burden of Disease Study 2016.[4] COPD=chronic obstructive pulmonary disease. LRTI=lower respiratory tract infections.

Our analytical approach is limited by several necessary assumptions (appendix). For example, HES-ONS reports some of the lowest postoperative death rates in the world. Basing our calculation on postoperative death rates with higher baselines than other high-income countries substantially increases our projections of total postoperative deaths.

Although there is a pressing need to expand surgical services to populations that are underserved, this expansion must be done in tandem with initiatives to reduce postoperative deaths. Funders and policy makers should prioritise research that aims to make surgery safer, particularly in LMICs. Routine measurement of surgical outcomes is essential to monitoring global progress in addressing the burden of postoperative deaths.

We declare no competing interests. DN and AB conducted the data analysis and interpretation and had access to all data. DN, JM, BB, AM, and AB drafted the manuscript. Collaborators listed in the appendix revised the manuscript, approved the final draft, and approved the decision to submit the manuscript. AB is the guarantor for this report. This Correspondence was funded by a National Institute for Health Research (NIHR) Global Health Research Unit Grant (NIHR 17–0799). The funder had no role in the study design, data collection, analysis, interpretation, or the writing of this Correspondence. The funder has approved the submission of this Correspondence for publication. The views expressed are those of the authors and not necessarily those of the National Health Service, the NIHR, or the UK Department of Health and Social Care.

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See Online for appendix

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Making all deaths after surgery count

Postoperative death is not unheard of, yet patients hope that such an outcome is unlikely when they require surgery themselves. Dmitri Nepogodiev and colleagues[1] estimate that, globally, at least 4·2 million people die each year within 30 days of a surgical procedure—a cause of death known as perioperative mortality, which was a focus of the *Lancet* Commission on Global Surgery.[2] Nepogodiev and colleagues used a complex model for perioperative mortality in different economic regions, making numerous assumptions and calculations since little data on perioperative mortality exists in any setting. The Article was considered controversial, receiving both criticism and praise on social media immediately after publication. Criticisms included the lack of risk adjustment, modeling methodology, and the absence of a link to cause of death. Although most of these criticisms were scientifically valid, critics uniformly missed the point.

Early in the 20th century, Ernest Amory Codman, a surgeon from Boston, began to use end result cards for each patient to record outcomes, including morbidity and mortality.[3] In 1911, the Massachusetts General Hospital (Boston, MA, USA) refused to accept his suggestions about the need for morbidity and mortality conferences and his outcome tracking system, thus Codman resigned.[3] Subsequently, morbidity and mortality conferences became standard procedure in all surgery units in high-income countries and have become an integral part of surgical culture. At the department, hospital, or facility level, risk adjustment is meaningful to understand the possible factors that might have led to morbidity and mortality. These discussions then form the basis of a root cause analysis and hopefully lead to improvements in surgical quality and safety. To be clear, we believe that risk adjustment is meaningful at the facility level in the context of quality and safety improvement and to allow for fair benchmarking given the diverse spectrum of surgical disease presentation.

The view of mortality at the national level differs from that at the facility level. National mortality data is used to assess the reality of the situation—ie, how many patients are dying. This concept is supported by the fact that maternal mortality, infant mortality, and under-5 mortality estimates are not risk-adjusted. In areas where perioperative mortality is high, the reality of death after surgery should be acknowledged and action should be taken to improve systems; people who have died should not be blamed for presenting to health care late, and researchers should not dismiss their deaths through risk adjustment. National data should be used to illustrate the realities of the human condition, rather than ignoring what makes us uncomfortable. Perioperative mortality in many countries is very high and should not be ignored.

Three changes are needed if universal health coverage and the Sustainable Development Goals are to be achieved. First, surgical facilities should record perioperative mortality and use this information for regular morbidity and mortality conferences and quality improvement processes. Second, perioperative mortality data that has not been risk-adjusted should be aggregated by ministries of health tracking progress on surgical, obstetric, and anaesthesia system strengthening to make strategic and tactical decisions about their national surgical, obstetric and anaesthesia plans.[4] Third, ministries of health should send this national data to WHO and the World Bank for transparent reporting in the World Bank World Development Indicators. We must first count the dead, then account for their death; only then can we improve care.

We declare no competing interests.

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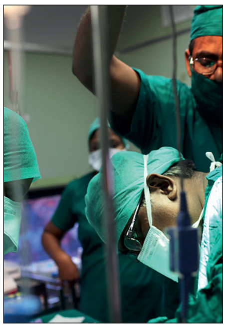
The AGE/Getty Images

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We welcome the important focus that Dmitri Nepogodiev and colleagues[1] bring to surgical safety. The authors estimate that globally, postoperative deaths account for 4·2 million deaths per year (7·7% of total deaths). Nepogodiev and colleagues project an expansion of surgical services in low-income and middle-income countries (LMICs) will result in an additional 1·9 million postoperative deaths per year, assuming that the postoperative mortality rate in LMICs remains constant while surgical services in these countries expand.

We question this assumption. Poor surgical outcomes in LMICs are often caused by surgery that is inadequate or too late. Poor availability of surgical services causes delays in patients seeking and receiving surgical care, with adverse effects on postoperative outcomes. More widely available surgical care will reduce these delays and can thus be expected to improve outcomes.

Furthermore, Nepogodiev and colleagues assume that surgical case-mix would remain broadly similar[1] as surgical services expand in LMICs. A high proportion of surgeries done in LMICs are emergencies, and thus the outcome of not operating is likely, or certain, death. 42·3% of operations done by membership-level trainees of the College of Surgeons of East, Central and Southern Africa (Tanzania) are emergencies (O'Flynn E et al, unpublished). This percentage is smaller in high-income countries. For example, 25·4% of operations in Irish public hospitals are considered emergency operations.[2] In LMICs, a substantial number of people are living with untreated elective surgical needs.[3] Therefore, expansion of elective surgical services would not result in a proportional increase in postoperative mortality.

In high-income countries, providing increased access to surgery has resulted in large reductions in mortality from surgical conditions.[4] Failure to expand access to quality assured surgical services in LMICs is much more dangerous than expansion.

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We read with interest the estimated global postoperative death rates by by Dmitri Nepogodiev and colleagues.[1] The authors highlighted the importance of routinely measuring surgical outcomes and expanding surgical services, together with initiatives to reduce postoperative death. Additionally, permanent disability should be considered when addressing the burden of surgical procedures. Permanent disability is particularly relevant with regard to neurosurgery, in which postoperative neurological changes could have important consequences in the patient's daily life. Moreover, permanent disability has a substantial effect on costs associated with postoperative treatments, such as productivity loss, work absenteeism, and the need for assistance.[2] Surgical outcomes should be evaluated using medical scales specific to each pathology and should measure the change in patient's clinical status. Patient-reported outcome measures should also be included for a more comprehensive and integrated outcome evaluation.[3]

Considering the complexity of each patient case is crucial when assessing surgical outcomes to monitor and improve quality of care. Surgical complexity also depends on the preoperative conditions and is a known risk factor for postoperative complications and negative outcomes.[4] A grading scale for brain tumour surgery (the Milan Complexity Scale[5]) was developed as an indicator of surgical complexity and is also used to estimate the risk of postoperative clinical worsening.[5] In conclusion, death might not be the worst postoperative outcome and the scientific community needs to learn how to measure all postoperative outcomes.

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Authors' reply

Safe surgery saves lives and is a cost-effective public health intervention, but it is associated with risks.[1] We estimated that, worldwide, more people die within 30 days of surgery than of any disease-specific category of death, with the exception of stroke and ischaemic heart disease.[2] Globally, disparities in postoperative death exist, with the majority of deaths occurring in low-income and middle-income countries (LMICs), despite only a minority of global surgeries being done there. High postoperative mortality rates indicate system failures, which are prevalent in LMICs. The role of the global surgical community is to support the development of safe surgery, to minimise postoperative deaths, and ensure all patients have the best chance of benefiting from surgery.

John Meara and colleagues emphasise the importance of tracking postoperative mortality rates to inform World Bank World Development Indicators. At present, few countries worldwide are able to collate high-quality postoperative mortality data. Until this situation improves, our evidence-informed estimates of global postoperative mortality rates provide the most accurate overview of the scale of the problem. Our data will inform discussion and support clinical and research priority setting and planning. Since data are scarce, the number of postoperative deaths at the national level and the causes of these deaths at the local level remain unclear.

We agree with Eric O'Flynn and colleagues who predict that as surgery expands, there will be a shift in LMICs from predominantly emergency surgery to increasing elective activity, and this change is likely to lead to lower postoperative mortality rates. However, rapid expansion of surgery is likely to be associated with some risk unless it is accompanied by the strengthening of health systems to support safe surgery. Our analysis highlights the urgent need for the development of adequate, safe, quality assured surgical infrastructure.

Silvia Schiavolin and colleagues propose a more integrated procedure-specific outcome assessment, including quality of life measures. Although this proposal would be ideal, at present it is unfeasible at the country level, where it is most needed. On the basis of this feedback, we plan to calculate country-level estimates of postoperative mortality rates to support national surgical planning and international research prioritisation. However, to calculate these estimates, increased collaboration among the global surgery community will be required, with the aim of reporting these national-level postoperative mortality rates through the World Bank World Development Indicators.

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Promoting critical appraisal skills

In the concluding section of most research reports, there is a unanimous opinion that more research is needed, and indeed, more research is often needed. However, Douglas Altman[1] once suggested that "we need less research, better research, and research done for the right reasons". It is now widely accepted that there is a massive amount of avoidable waste in medical research because of inadequate research prioritisation, conceptualisation, design, execution, analysis, and reporting.[2,3] These deficiencies reflect poor training in research design, which is almost an inevitable consequence of inadequate mentoring of students who are expected to do research as part of their education.

Encouraging undergraduate students to believe that an efficient way of learning about research is by doing it can result in frustration and wasted time, effort, and money; it might also encourage students to learn about one research technique only. However, inadequate resources for reliable advice and knowledgeable supervision mean that this approach is likely to produce low-quality research using flawed methods, which can use up most of a school's budget for research training.

Evidence-based skills help clinicians gain, assess, apply, and integrate new knowledge,[4] but only a few clinicians need the skills to actually do research. These principles led the medical school at the University of Queensland to reconsider how best to educate medical students about research.

The University of Queensland decided to switch the curriculum from requiring every student to do a research project to requiring them, instead, to critically appraise a topic, incorporating the following steps: (1) selecting a clinical question for investigation; (2) describing the searches used to identify relevant studies; (3) choosing the two best studies identified and justifying the selection of one of them; (4) appraising the validity of the study; and (5) summarising how the results of the study apply to the patients with the condition that had prompted the original clinical question. This change was successful because it made students more interested in research and it was much less resource-intensive.


Prisma by Dukas/Getty Images

8 years ago, one of us (IC) accepted an invitation to address medical students in the Gaza Strip. The talk began by asking students which they believed that clinicians should learn: how to do research or how to judge the quality and relevance of research. Most students felt that learning how to judge research is more beneficial.

The expectation that medical and other health-care professional students should do research needs

THE LANCET

Supplementary appendix

This appendix formed part of the original submission. We post it as supplied by the authors.

Supplement to: Nepogodiev D, Martin J, Biccard B, Makupe A, Bhangu A. Global burden of postoperative death. *Lancet* 2019; **393:** 401.

Deaths within 30 days of surgery in low-, middle-, and high-income countries

*NIHR Global Health Research Unit on Global Surgery**

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S1 Appendix: Methods and results

Approach to calculating postoperative deaths

The number of postoperative deaths occurring in high income countries (HICs) and low- and middle-income countries (LMICs) were separately calculated. These two figures were then summed to calculate a global total for deaths within 30 days of surgery.

The equation to calculate postoperative deaths in HICs was:

$$\sum_{1}^{14} c_{HIC} \times x_{HIC} \times y_{HIC}$$

Where:

c_{HIC} = total operations performed annually in HICs

x_{HIC}= proportion of HIC case-mix belonging to particular specialty

y_{HIC}= postoperative death rate in HIC settings for particular specialty

The equation to calculate postoperative deaths in LMICs was:

$$\sum_{1}^{14} c_{LMIC} \times x_{LMIC} \times y_{HIC} \times m$$

Where:

c_{LMIC} = total operations performed annually in LMICs

x_{LMIC}= proportion of LMIC case-mix belonging to particular specialty

y_{HIC}= postoperative death rate in HIC settings for particular specialty

m = postoperative death rate adjustment constant

Data sources

Surgical volume: The c constants are the estimated number of operations performed in HICs (c_{HIC}) and LMICs (c_{LMIC}). The total operations performed in HICs versus LMICs are not readily available, therefore health expenditure per capita was used as a proxy. Health expenditure per capita ≥$1000 per year was assumed to indicate HICs, and health expenditure <$1000 per year was assumed to represent LMICs. On this basis, 187,000,000 (95% confidence interval (CI) 155,800,000 to 224,500,000) operations are performed annually in HICs and 125,900,000 (95% CI 83,900,000 to 202,300,000) are performed in LMICs[1].

Case-mix: A key reason for differences in raw postoperative death rates between HICs and LMICs might be operative case-mix[2,3]. We therefore established separate estimates for case-mix in HICs (variable x_{HIC}) and LMICs (variable x_{LMIC}). Since there are no readily available LMIC national surgical registries, to estimate LMIC case-mix we have used data from the African Surgical Outcomes Study (ASOS)[2]. This prospective cohort study captured data on 11,422 patients across 247 hospital in 25 countries. ASOS reported case-mix split into 15 surgical specialties; we have merged 'thoracic (lung)' and 'thoracic (gut)' to produce a list of 14 specialties (S1 Table).

For HICs, case-mix was based on a single national registry of surgical activity from a universal health system: England's Hospital Episodes Statistics linked Office of National Statistics (HES-ONS) dataset. To produce HIC case-mix categories that would be directly comparable to the LMIC case-mix data, we first cleaned the 2010 HES-ONS to remove non-surgical (e.g. endoscopic and dental) procedures. This removed 28.8% (374/1,297) procedure codes. The remaining 923 codes were then categorised into the 14 specialties derived from ASOS to estimate case-mix (S1 Table).

HIC postoperative death rates: 30-day postoperative death rates were separately derived for each of the 14 specialties (variable y). For our main analysis we used the HES-ONS dataset. Postoperative death rates were defined as total deaths within 30 days of a procedure as a proportion of finished consultant episodes in that specialty. The overall postoperative death rate in the HES-ONS dataset was 1.09% (37,645/3,438,242).

Several studies over the past decade have reported national and international 30-day postoperative death rates, but their case-mix has varied. As a sensitivity analysis, we further tested our base model to explore totals for postoperative death using other recently reported baseline postoperative death rates from high income settings:

- An analysis of 298,772 non-cardiac surgery cases from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database from 2005-2007 found the baseline postoperative death rate to be 1.34%[4]. Since per-specialty estimates were not available, we proportionately scaled the HES-ONS per-specialty rates by the ratio of the NSQIP (1.34%) to HES-ONS mortality (1.09%). However, since the NSQIP cohort excluded cardiac and obstetric surgery, the HES-ONS postoperative death rates were used for these specialties.
- The European Surgical Outcomes Study (EUSOS) captured data on patients undergoing non-obstetric, non-day case surgery across 498 hospitals in 28 European countries[3]. The overall postoperative death rate was 3.99% (1855/46539). Since the specialty categories reported in EUSOS did not match up with the categories established from ASOS and HES-ONS, we again proportionately scaled the HES-ONS per-specialty postoperative death rates based on the ratio of EUSOS (3.99%) to HES-ONS reported deaths (1.09%). Again, as the EUSOS cohort excluded obstetric surgery, the HES-ONS postoperative death rate for obstetrics was used.

Mortality adjustment: Although many studies have reported higher postoperative death rates in LMICs compared to HICs[5,6], most studies are difficult to interpret as most LMIC studies are single-centre or single-country and do not allow for a direct comparison with HIC data. The GlobalSurg Collaborative has published two prospective multicentre studies (GS1 and GS2) directly comparing postoperative death rates in LMICs versus HICs. In GS1, in 10,745 patients undergoing emergency abdominal surgery across 357 centres in 58 countries, the postoperative death rate was 6.8% (287/4,207) in LMICs versus 4.5% (291/6,538) in HICs[7]. GS2 included 12,539 patients who underwent either emergency or elective abdominal surgery across 343 hospitals in 66 countries, and showed that postoperative postoperative death rates were 2.5% (125/5,098) in LMICs versus 1.5% (110/7,130) in HICs[8]. However, since these GlobalSurg studies were limited to abdominal surgery, we wished to identify comparative data for this analysis that would be more broadly generalizable across all surgeries. A large systematic review by Bainbridge et al of global postoperative death across all surgical specialties found postoperative death rates to be 0.2% (589/309,245) in LMICs compared to 0.1% (5,981/6,738,683) in

HICs[9]. Therefore, the relative risk for postoperative death for LMICs versus HICs was 2.14 (95% CI 1.96 to 2.32).

At present, specialty-specific postoperative death rates have not been collected across a representative range of LMICs. Therefore, we applied Bainbridge et al's estimate for increased risk of postoperative death in LMICs to adjust our baseline HIC postoperative death rates (constant m).

All-cause deaths: The Global Burden of Disease (GBD) study estimated that in 2016 there were 54,698,600 deaths worldwide from all causes[10]. This figure was used as the denominator to calculate the proportion of total global deaths that occur within 30 days of surgery.

Main analysis

Our main analysis utilised HIC condition-specific postoperative death rates based on the HES-ONS dataset (S1 Table). We used the point estimates for surgical volume (c_{HIC}=187,000,000, c_{LMIC}= 125,900,000) and Bainbridge's relative risk of death in LMICs compared to HICs (m=2.14). Based on these parameters, we estimated that at least 4.2 million people die within 30 days of surgery each year (S2 Table).

To place 4.2 million annual postoperative deaths in context, we compared this figure to a ranked list of the ten leading global causes of death reported in GBD 2016 (Figure 1).

Sensitivity analysis

To determine the impact of using different baseline rates of postopoerative death to those provided by HES-ONS, we tested different scenarios based on the estimating HIC postoperative death rates from NSQIP and EUSOS (S2 Table).

Projection for expanded surgical capacity

At present, around 4.8 billion people worldwide lack timely access to safe and affordable surgery[11]. It is estimated that there is an annual unmet need for 143 million procedures in LMICs[12]. Increasing access to surgery is therefore a priority. In order to understand the implications of an increase in surgical volume, we estimated the number of additional postoperative deaths that might occur if 143 million additional procedures were performed in LMICs at the current rate of disparity in postoperative death rates.

S2 Appendix: Strengths and limitations

This analysis has necessarily required a series of assumptions to be made regarding global surgical volume, surgical case-mix, post-operative death rates in high income countries (HIC), adjustment for mortality from HICs to low- and middle-income countries (LMICs), the need for expansion of surgery in LMICs, and comparisons of postoperative death rates to the leading causes of death reported in the Global Burden of Disease (GBD) study. In this Appendix the strengths and weaknesses of each underlying assumption are discussed. Despite these limitations, we believe that this study represents the best estimate of total postoperative deaths possible using existing data. Moreover, our modelling is a baseline for future high-quality data to feed in to.

Surgical volume

Global surgical volume was most recently estimated in a modelling study by Weiser et al[1]. Surgical volume data were obtained for 66 countries. A model based on total health expenditure per capita and population was developed, to extrapolate surgical volume for other countries for which surgical volume data were not available. The authors provided a breakdown of total surgical volume by total health expenditure per capita: very low (≤$100), low ($101-400), middle ($401-1000), and high (>$1000).

A total of 136 of 139 LMICs (as designated in the DAC List of ODA Recipients) and 14 of 55 HICs were recorded by Weiser et al as having very low, low, or middle levels of total health expenditure per capita. Therefore, within the constraints of the data available, LMIC surgical volume was taken as the sum of operations performed in all countries with total health expenditure per capita ≤$1000. HIC surgical volume was based on total surgical volume in countries with expenditure >$1000 per capita.

The Weiser study was modelled to provide surgical volume for 2012. Given that global surgical volume expanded from an estimated 226 million cases per year in 2004 to 313 million cases per year in 2012, it is likely that surgical volume has continued to increase, with significantly more cases performed in 2018 than Weiser's 2012 estimate. This would lead to an under-estimation of total postoperative deaths.

Surgical case-mix

For HICs, case-mix was based on a national registry of surgical activity from a universal health system: England's Hospital Episodes Statistics (HES). Although more recent operative volume statistics are available, case-mix estimates were based on the 2010 HES dataset to maintain consistency with use of the Hospital Episodes Statistics linked Office of National Statistics (HES-ONS) dataset for estimates of postoperative death rates. The HES dataset captures all procedures performed within National Health Service (NHS) hospitals, accounting for over 90% of total surgical volume in England. HES does not capture data for procedures performed in private hospitals. Since private hospitals in England typically focus on low to intermediate risk surgery, the HES dataset may overestimate volume in higher-risk surgical specialties. This would be likely to lead to an overestimation of total postoperative deaths.

The assumption that surgical case-mix in England is representative of case-mix across all other HICs represents a significant limitation since differing epidemiological profiles across HICs are likely to lead to differing surgical case-mix. The effect of this on the estimate of total postoperative deaths is uncertain.

There are no readily available LMIC national surgical registries. Therefore, the African Surgical Outcomes Study (ASOS) was used to estimate LMIC case-mix. This cohort was based on prospective data collection across 247 hospital in 25 African countries. Inevitably larger hospitals are more likely to participate in international studies and the ASOS data may not reflect the case-mix across all surgical units in Africa. Moreover, it is unknown how generalisable case-mix derived in Africa is to LMICs on other continents.

Postoperative mortality in high income countries

For the primary analysis, baseline HIC postoperative death rates were extracted from England's HES-ONS dataset, a national registry from a universal health system. The most recent publicly available HES-ONS linked dataset dates from 2010. Postoperative death rates in England have decreased since 2010[6], therefore using HES-ONS may either overestimate HIC postoperative death rates in 2018.

There are few robust national estimates of postoperative death rates encompassing the full scope of surgical activity. Amongst those postoperative death rates that are reported, the lowest is 0.54%, from the New Zealand the Perioperative Mortality Review Committee[13]. The highest rate is 3.99%, from the European Surgical Outcomes Study (EUSOS)[3]. The HES-ONS postoperative death rate (1.09%) is therefore amongst the lowest reported and is similar to the 1.34% rate reported by the American College of Surgeons National Surgical Quality Improvement Program (NSQIP)[4]. Variation in reported postoperative death rates is partly a reflection of subtle differences in inclusion criteria, for example whether day-case procedures contribute to the reported postoperative death rate.

The main analysis utilised postoperative death rates based HES-ONS, as this dataset offered the greatest granularity, providing speciality-specific rates for the full scope of surgical activity, including day case surgery and Caesarean section. Specialty-specific postoperative death rates were important to obtain in order to account for differences in case-mix between HICs and LMICs.

In order to explore the effect of adopting higher baseline HIC postoperative death rates than that derived from HES-ONS, we performed a sensitivity analysis. We tested our base case model to estimate totals for postoperative death using the NSQIP and EUSOS data (S2 Table).

Postoperative death rate adjustment from high to low/middle income countries

Bainbridge et al study is the most extensive review of postoperative death rates across all surgical specialties. This systematic review included data from 87 studies on 21.4 million patients undergoing surgery with general anaesthetic. Although the baseline postoperative death rates identified by the Bainbridge study were low (0.2% in LMICs and 0.1% in HICs), the relative risk (2.14) for death following surgery in LMICs versus HICs was broadly consistent with the findings of the prospective, international GS1[7] (RR 1.53), GS2[8] (1.59), and ASOS/ISOS[2,14] (RR 2.20) studies. Since the GS1 and GS2 studies only included patients undergoing abdominal surgery, the Bainbridge study offers a more generalizable estimate for postoperative death rate adjustment, and is similar to the ASOS/ISOS comparison.

Using a single estimate for postoperative death rate adjustment for all surgery types may lead to underestimation of postoperative death rates for some specific procedures. For example, the postoperative death rate for caesarean section in the ASOS study was 0.53% (20/3,792) compared to 0.01% (16/158,229) in HES-ONS. Therefore, the estimate from the Bainbridge study that we have used to adjust HES-ONS mortality rates may be conservative, underestimating total postoperative deaths.

Need for expansion of surgery

Rose et al calculated the global unmet need for surgery by estimating the total required surgical volume and subtracting the current volume of surgery performed. Required surgical volume was derived by taking prevalence for 21 disease categories from the 2010 Global Burden of Disease (GBD) study and multiplying this by the rates of surgery for each disease category, based on New Zealand registry data. Whilst the study provides an estimate for the total need for surgery by surgery type, equivalent figures by surgery type for unmet need are not provided. Therefore it was not possible to determine the case-mix of the unmet need for surgery. Consequently, we assumed that in the event of all unmet surgical need being addressed, LMIC surgical case-mix would remain broadly similar to that recorded in the ASOS dataset. The effect of this on our estimate for total postoperative deaths that might occur if there were no unmet need for surgery is uncertain, as this depends on whether unmet need is predominantly for procedures with low or high postoperative death rates.

Global Burden of Disease study comparison

The main output from this study was an estimate for the absolute number of postoperative deaths. In order to put this figure in to context it was compared to the numbers of deaths associated with the top ten causes of death in GBD[10]. This comparison should be interpreted with caution. As postoperative death is not a recognised cause of death in GBD studies, each postoperative death has been double counted across one of the 249 causes of death reported by GBD, most likely the underlying condition for which the patient was operated. For example, the IHD category may include patients who died following complications of cardiac surgery, or as a result of a postoperative myocardial infarct. Similarly, the lung cancer category may include patients who die as a result of complications following surgery for lung cancer, and the stroke category is likely to include some patients who die as a result of postoperative stroke. However, this risk of overlap is common for many categories of global mortality, and represents a ubiquitous limitation of estimating global burden of condition-specific mortality more generally.

Importantly, we do not seek to imply causality between patients undergoing surgery and dying within 30 days. Some postoperative deaths may be entirely unrelated to the patient's surgery, for example, deaths resulting from trauma. For some patients postoperative death represents a failure of surgery as a treatment strategy; for instance, a patient who succumbs despite attempted surgery for a ruptured abdominal aortic aneurysm. Many postoperative deaths however occur as a result of postoperative complications. Whilst on a global level we are unable to differentiate between these different categories of postoperative death, it is important to bring the overall scale of the postoperative death to policy makers' attention since many postoperative deaths could be prevented with improved perioperative care.

S1 Table: Baseline case-mix and postoperative death rates by specialty

Surgical specialty	Case-mix HIC* (x_{HIC})	Case-mix LMIC** (x_{LMIC})	Postoperative death rate HIC* (y_{HIC})
Breast	2.5%	2.1%	0.2%
Cardiac	1.0%	0.5%	2.9%
Gynaecological	6.0%	12.1%	0.1%
Head and neck	10.2%	4.2%	0.2%
Hepatobiliary	2.1%	1.6%	0.9%
Lower gastrointestinal	5.9%	8.7%	1.7%
Neurosurgery	4.2%	2.3%	1.2%
Obstetric	4.6%	35.2%	0.0%
Orthopaedic	21.0%	16.4%	1.0%
Thoracic	0.9%	1.4%	6.1%
Upper gastrointestinal	1.6%	2.8%	4.8%
Urology	6.5%	5.2%	0.4%
Vascular	3.7%	2.2%	5.4%
Other	29.7%	5.1%	1.0%

*High income country (HIC) baseline estimates based on the Hospital Episode Statistics linked Office of National Statistics (HES-ONS) dataset

**Low- and middle-income country (LMIC) baseline case-mix based on the African Surgical Outcomes Study (ASOS)

S2 Table: Estimates of total postoperative deaths

Source for baseline postoperatice death rate	Postoperative deaths			Proportion of global mortality attributable to postoperative death
	LMIC	HIC	Total	
HES-ONS	2,180,787	2,047,446	4,228,233	7.7%
Projection if surgical provision expanded	4,099,878	2,047,446	6,147,324	11.2%
NSQIP	2,580,824	2,421,633	5,002,457	9.1%
Projection if surgical provision expanded	4,851,948	2,421,633	7,273,581	13.3%
EUSOS	7,553,262	7,111,492	14,664,755	26.8%
Projection if surgical provision expanded	14,200,129	7,111,492	21,311,621	39.0%

EUSOS: European Surgical Outcomes Study; HES-ONS: Hospital Episode Statistics linked Office of National Statistics dataset; HIC: high income countries; LMIC: low- and middle-income countries; NSQIP: American College of Surgeons National Surgical Quality Improvement Program

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