Title page

The African Surgical Outcomes Study: a 7-day prospective observational cohort study

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Research in context

Evidence before this study

Safe, accessible and affordable surgery is a global health priority. It is estimated that 5 billion people do not have access to safe and affordable surgery, whilst an additional 143 million surgeries each year are needed in low and middle-income countries (LMICs) to address this need. However, there are limited surgical outcomes data from LMICs, and particularly few data from Africa. Two recent observational cohort studies only included a small number of African countries, with a limited range of surgeries reported. Increasing access to surgery is a priority in Africa, however it is essential to ensure that the surgery is safe, and that unnecessary perioperative morbidity and mortality is prevented. Because of the limited data of surgical outcomes data in Africa, there is an urgent need for a robust epidemiological study of perioperative patient outcomes to inform the global surgery initiative.

Added value of this study

The African Surgical Outcomes Study provides data from 25 African countries for all in-patient surgeries. One in five surgical patients in Africa develops a perioperative complication, following which, one in ten patients will die. Our findings show that, despite being younger with a low risk profile, and lower complication rates, patients in Africa are twice as likely to die following surgery when compared with outcomes at a global level. African surgical hospitals are under-resourced with a median combined total of specialist surgeons, obstetricians and anaesthesiologists of 0.7 ([25th/75th centile] 0.2-1.9) per 100,000 population, far below the recommended number identified by the Lancet Commission on Global Surgery. The volume of surgical procedures is also very low at 212 (65-578) procedures per 100,000 population each year. Most surgical procedures are performed on an urgent or emergency basis, and one third are Caesarean deliveries. Importantly, 95% of deaths occur after surgery, indicating the need to improve the safety of perioperative care.

Implications of all the available evidence

Previous studies have provided only limited data on surgical outcomes in Africa, through limited country participation and inclusion of selected surgical procedures. The African Surgical Outcomes Study provides a detailed insight into this problem. Our findings suggest a high incidence of potentially avoidable deaths amongst low-risk surgical patients, largely due to a failure to identify and treat life-threatening complications in the perioperative period. Limited availability of human and hospital resources may be a key factor. Despite the positive impact of the global safe surgery campaign, our findings show that surgical outcomes will remain poor in Africa, until the perioperative care of patients with deteriorating physiological function is addressed, and sufficient resources are available to provide this care. A

continent-wide quality improvement strategy to promote effective perioperative care may save many lives after surgery in Africa.

Abstract

Background

There is a need to increase access to surgical treatments in African countries, but perioperative complications represent a major global healthcare burden. There are few data describing surgical outcomes in Africa.

Methods

Seven-day, international, prospective, observational cohort study of patients ≥18 years undergoing in-patient surgery in Africa. The primary outcome was in-hospital postoperative complications. The secondary outcome was in-hospital mortality. Data are presented as median (25^{th}/75^{th} centile) and n (%).

Findings

11422 patients were recruited from 247 hospitals during the national cohort weeks between February and May 2016 in 25 African countries. Hospitals served a median population of 810,000 (200,000 - 2,000,000) people, with a combined number of specialist surgeons, obstetricians and anaesthetists totalling 0.7 (0.2-1.9) per 100,000 population. Hospitals recruited 29 (10-70) patients, equivalent to 212 (65-578) surgical procedures per 100,000 population each year. Patients were younger (38·5 [16·1] years), with a lower risk profile (American Society of Anesthesiologists score 1 [1-2]) than reported in high income countries. 1253 (11·0%) patients were infected with human immunodeficiency virus. 6504 procedures (57%) were urgent or emergent. The most common procedure was Caesarean delivery (3792 patients, 33%). Complications occurred in 1977/10885 (18·2%) patients but overall mortality was more than twice the global average (239/11193 [2·1%]), with 225/239 (94·1%) deaths occurring after the day of surgery. Infection was the commonest complication (1156/10970, 10·2%) with 112 deaths (9·7%). Complications were associated with prolonged hospital stay (3 [2-5] days vs 6 [4-13] days; p<0·001).

Interpretation

Despite a low risk profile and low complication rates, patients in Africa are twice as likely to die after surgery when compared to the global average. Initiatives to increase access to surgical treatments in Africa, must be coupled with improved surveillance for deteriorating physiology amongst patients who develop postoperative complications and the resources necessary to achieve this objective.

Funding

Medical Research Council of South Africa.

Introduction

The surgical population represents a major global health burden with more than 300 million surgical procedures performed annually,[1] and an early postoperative mortality of up to 4%.[2,3] However, it has been estimated that 5 billion people are unable to access safe surgical treatments,[4] 94% of whom live in low and middle-income countries (LMICs).[4] Estimates suggest that globally, an additional 143 million surgical procedures are required each year, many of which are in Africa.[4] Surgery is a cost-effective and core component of universal health coverage,[5,67] but it needs to be safe.[4] Known barriers to the provision of safe surgical treatment in Africa include low hospital procedural volumes,[8] low numbers of hospital beds,[9] and a paucity of operating theatres,[10] all of which are compounded by the geographical remoteness of many surgical hospitals and a lack of adequately trained staff.[11,12] The Lancet Commission on Global Surgery was established to develop strategies for safe, accessible and affordable surgical care, but implementation of this strategy requires robust epidemiological data describing patterns of surgical activity and subsequent patient outcomes.[7,13]

Data describing surgical outcomes in Africa are particularly limited, and the findings of international studies are dominated by activity in high-income countries, with little participation from African countries.[9,14] Furthermore, few African countries have national registries or audit systems to monitor surgical procedures and subsequent outcomes. Low Human Development Index (HDI) countries, many of which are African, are believed to have significantly higher perioperative mortality but this remains unconfirmed.[14,15] The effect of population disease burden on the pattern of surgical outcomes in Africa is also unknown. Compared to high income countries, there is a preponderance of communicable diseases and injuries,[14,16-18] of which human immunodeficiency virus (HIV) is the leading cause of life years lost in Africa.[18]

To improve both the provision and quality of surgical treatments in Africa, we need a detailed understanding of the volume of surgical treatments currently performed, the surgical resources available, and the associated patient outcomes.[4] The objective of the African Surgical Outcomes Study (ASOS) was to provide robust epidemiological data describing the volume of surgical activity, perioperative outcomes, and surgical workforce density in Africa, which are comparable to published international surgical outcomes data.[9]

Methods

Study design

This was a seven day, international multicentre prospective observational cohort study of patients ≥18 years undergoing any form of in-patient surgery in hospitals in African countries. This study was registered on the South African National Health Research Database (KZ_2015RP7_22), and on ClinicalTrials.gov (NCT03044899). Our findings are reported in accordance with the STROBE statement.[19] A collaborative network of over 1000 healthcare professionals was established across Africa, through personal invitations to colleagues, invitations to surgical and anaesthesia societies, a website (www.asos.org.za) and a twitter feed (@africansos). BMB made country visits where possible to meet with local study investigators. A website provided investigator support, in the form of a regularly updated 'frequently asked questions' webpage, the protocol, case report forms (CRFs), and an outcomes definitions document in English and French (www.asos.org.za).

Setting and participants

In each country, we aimed to recruit as many hospitals as possible using a convenience sampling strategy. For inclusion of country data in the study we required; i) data from at least 10 hospitals or at least half of the surgical centres, if fewer than 10 in the country, ii) submission of the total number of eligible patients during recruitment week, and iii) provision of data describing at least 90% of the eligible patients from each site. Each country selected a single recruitment week between February and May 2016. All patients undergoing elective and non-elective surgery with a planned overnight hospital stay following surgery during the study week were eligible for inclusion. Patients undergoing planned day surgery, or radiological procedures not requiring anaesthesia were excluded. Regulatory approval varied between countries, with some requiring ethics approval and others only data governance approval. The primary ethics approval was from the Biomedical Research Ethics Committee of the University of KwaZulu-Natal, South Africa (BE306/15). All sites approved a waiver of consent, except the University of the Witwatersrand, South Africa which required informed consent from all patients, with deferred consent for patients who could not give consent prior to surgery.

Variables and data

Hospital-specific data included the number of hospital beds, number of operating rooms, number of critical care beds, and numbers of anaesthetists, surgeons and obstetricians working in each hospital. We replicated the design of a recent global study, with an almost identical patient dataset to allow a direct comparison of surgical outcomes data from Africa with surgical outcomes at a global level.[9,20] Complications were assessed according to predefined criteria and graded as mild, moderate or severe.[20] Data describing consecutive patients were collected on paper case record forms until hospital discharge, censored at 30 days following surgery for patients who remained in hospital. Data were anonymised

during the transcription process using REDCap (Research Electronic Data Capture) tools hosted by Safe Surgery South Africa. REDCap is a secure, web-based application designed to support data capture for research studies.[21] Soft limits were set for data entry, prompting investigators when data were entered outside these limits. In countries with poor internet access, mobile phones were used for data entry, or CRFs were forwarded to BMB, for entry by Safe Surgery South Africa. National leaders confirmed the face validity of the unadjusted outcome data for their countries, and hospital level data were evaluated statistically to confirm plausibility.

Outcome measures

The primary outcome measure was in-hospital postoperative complications defined according to the consensus definitions by Jammer et al.[20] The secondary outcome measure was in-hospital mortality. All outcomes were censored at 30 days for patients who remained in hospital. Outcomes data are presented at a national, regional (central, eastern, northern, southern, western African, and Indian Ocean Islands) and continental level. The outcomes definitions document is in the Supplementary Appendix.

Statistical analysis

There was no prespecified sample size, as the aim was to recruit as many hospitals as possible, and ideally every eligible patient from recruiting hospitals. We anticipated that a minimum sample size of 10,000 patients would provide a sufficient number of events for construction of a robust continental logistic regression model.[22] Although this study can provide an estimate of continental mortality, it was not powered to detect differences in mortality between countries. During the process of hospital recruitment and data collection, we realised that our predefined criteria for including a national patient sample were too strict for many countries, despite formal acceptance by the national leaders of these requirements before the study began. Prior to analysis, we took the decision to present the data describing the full cohort, and include a per-protocol analysis of the predefined representative sample for comparison.

Categorical variables are described as proportions and compared using Fisher's exact test. Continuous variables are described as mean and standard deviation, or median and $25^{th}/75^{th}$ centile, and compared using t-tests. For country specific mortality comparison, we constructed a multivariable logistic model that included all potential risk factors associated with in-hospital mortality. These included; age, smoker status, gender, American Society of Anesthesiologists (ASA) category, preoperative chronic comorbid conditions (coronary artery disease, congestive heart failure, diabetes mellitus, cirrhosis, metastatic cancer, hypertension, stroke, chronic obstructive pulmonary disease, HIV, chronic renal disease), the type of surgery, urgency of surgery (elective, urgent or emergency) and the severity of surgery (minor, intermediate or major). To avoid collinearity of potential risk factors, variables with variance inflation factor >2 were excluded. For all analyses, we performed a complete case analysis, excluding patients with missing data

from the analysis. South Africa, the country with the largest number of observed events was used as the reference country. Orthopaedic surgery as the largest noncardiac, non-obstetric surgical category was used as surgical reference category. Restricted cubic splines were used to fit continuous variables.[23] Model performances were evaluated by assessing the calibration and discrimination of the model. A smooth, nonparametric calibration line was created with the LOESS algorithm (i.e. a locally weighted scatterplot smoothing) to estimate the observed probabilities of in-hospital mortality in relation to the predicted probabilities. Discrimination was quantified by calculating the concordance statistic (c-statistic) completed with optimism,[24] which relates to both model coefficients estimation and over-fitting (e.g. selection of predictors, categorization of continuous predictors). We conducted four sensitivity analyses of the association between preoperative risk factors and mortality. These included; i) a per-protocol sensitivity analysis of only the patients from the hospitals which provided hospital facility data, ii) a full case sensitivity analysis, with multiple imputation of missing data to test for potential bias associated with missing variables,[25] and iii) two further analyses which explored the effect of the hospital facility level or university-affiliation on mortality. In these two analyses, we either forced hospital facility level or university-affiliation into the model. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 24 (SPSS Inc., Chicago, IL, USA) and R statistical software package version 3.4 (R Foundation for Statistical Computing, Austria).

Role of funding source

The study was funded by an investigator initiated research grant from the Medical Research Council of South Africa awarded to BMB. The study website (www.asos.org.za) and the data repository was maintained by Safe Surgery South Africa and the South African Society of Anaesthesiologists. These organisations played no role in the study design, data acquisition, data analysis or writing of the paper.

BMB, YLM and TME had full access to the data. BMB and RMP had responsibility for submission of the manuscript.

Results

Country and hospital data

247 hospitals participated in 25 African countries (Figures 1 and 2). These included 14 low-income countries (Benin, Burundi, Congo, Democratic Republic of the Congo (DRC), Ethiopia, Gambia, Madagascar, Mali, Niger, Senegal, Tanzania, Togo, Uganda, and Zimbabwe) and 11 middle-income countries (Algeria, Cameroon, Egypt, Ghana, Kenya, Libya, Mauritius, Namibia, Nigeria, South Africa, and Zambia). Hospital level data were submitted for 216 of 247 (87·4%) participating hospitals. 173/216 (80·1%) were government-funded hospitals, 28/216 (12·0%) privately funded, and 15/216 (6·9%) jointly funded hospitals. 103/212 (48·6%) were university-affiliated hospitals. 45/216 (20·8%) were primary-level hospitals (defined as mainly obstetrics and gynaecology and general surgery), 68/216 (31·4%) were secondary-level hospitals (defined as highly differentiated by function with 5 to 10 clinical specialities), and 103/216 (47·7%) were tertiary-level (defined as specialised staff or technical support) hospitals.[26] Each hospital served a median population of 880 000 (200000-2000000) people, with 300 (140-545) beds, 6 (2-7) operating rooms and 3 (0-7) critical care beds providing invasive ventilation. The ratio of critical care beds to hospital beds was 0·9% (0-2·0). Hospitals were staffed by 3 (1-8) specialist surgeons, 1 (0-5) specialist anaesthetists, and 2 (0-5) specialist obstetricians, with a median of 0·7 (0·2-1·9) of any specialist per 100,000 population. The median number of surgical procedures per hospital for the study week was 29 (10-71).

Patient data

11422 patients were recruited (Figure 2). The patient characteristics, perioperative complications and mortality are shown in Table 1. Most patients had a low perioperative risk profile. They were young (38·5 years [16·1]), with an American Society of Anesthesiologists (ASA) physical status score of 1 [1-2]). The most common comorbidities were hypertension (1863 patients, 16·3%) and HIV (1253 patients, 11·0%). Most surgery was urgent or emergent (6504/11378, 57%). The most common procedure was Caesarean delivery (3792/11393, 33·3%). The World Health Organisation Safe Surgery Checklist or a similar surgical checklist was used in 6183/10836 (57·1%) of surgeries.

Patient outcomes following surgery are shown in Table 2. There were 239 deaths after surgery (2·1%), only 14 (5·9%) of which occurred on the day of surgery. The median time of death was 5 [2-11] days postoperatively. Postoperative complications occurred in 1977/10885 (18·2% [95% CI 17·4-18·9]), with a mortality of 188/1970 (9·5% [95% 8·2-10·8%]). 321/1972 (16·3%) patients with postoperative complications were admitted to critical care to treat these complications, of whom 255/321 (79·4%) were admitted to critical care immediately after surgery. Complications were associated with prolonged hospital stay (3 [2-5] days vs 6 [4-13] days; p<0·001). Individual postoperative complications are shown in Table 3. Infectious complications were most common whilst cardiovascular complications

were associated with the highest mortality (110/190, 57·9%). Cardiac arrest was associated with a 101/113 (89·4%) in-hospital mortality. The proportional contribution of non-communicable diseases, infection, trauma and caesarean delivery as the primary indication for surgery to mortality and postoperative complications is shown in Table 4. Non-communicable diseases were the most common indication for surgery, however significantly more postoperative complications and death followed surgery for infection and trauma.

The country specific data are shown in Supplementary Table 1. The model to describe mortality had poor discrimination for mortality (c-statistic corrected for optimism of 0·53, Brier of 0·0222 for mortality) when based on the countries alone. However, the adjusted model for country specific mortality showed good discrimination for mortality (c-statistic corrected for optimism of 0·83, Brier of 0·0222) (Supplementary Table 2). The calibration plot for in-hospital mortality is shown in Supplementary Figure 1. After risk-adjustment, most countries had a similar risk of mortality. Postoperative mortality was strongly associated with increasing ASA grade, urgency of surgery, and grade of surgery (intermediate and major). Gastrointestinal, hepatobiliary and neurosurgery were associated with increased mortality.

When compared to a recent global epidemiological study of elective surgery (International Surgical Outcomes Study, or ISOS),[9] the elective surgical patients in the ASOS cohort were younger, had a lower risk profile, and underwent more minor surgery. Patients in ASOS experienced fewer postoperative complications (Supplementary Table 3). The comparison between the postoperative mortality, postoperative complications, and mortality following postoperative complications, after elective surgery in the ISOS high-income and LMICs, and the African countries of the ASOS cohort, is shown in Figure 3 and Supplementary Figure 2. Mortality amongst surgical patients in Africa was twice the global average represented by the ISOS cohort.

The per-protocol analysis of the hospital data, patient data, patient outcomes, postoperative complications and the primary indication for surgery are shown in Supplementary Tables 4-8. The regional country participation is shown in Supplementary Figure 3, and the African regional outcomes are shown in Supplementary Table 9.

Sensitivity analyses

The outcomes reported according to hospital facility level are shown in Supplementary Table 10. The per-protocol sensitivity analysis of only the patients from the hospitals which provided complete hospital facility data are shown in Supplementary Table 11. The full case sensitivity analysis, with multiple imputation of missing data to test for potential bias associated with missing variables is shown in Supplementary Table 12. Both these sensitivity analyses provided similar results to the primary multivariable analysis. The sensitivity analyses which explored the effect of the hospital

facility level or university-affiliation on mortality are shown in Supplementary Tables 13 and 14. Hospitals of a higher facility level were independently associated with increased mortality, but university-affiliation was not. None of the sensitivity analyses have altered our overall findings.

Discussion

Key findings

The principal finding of this study was that surgical patients in Africa are younger, with a low risk profile and low complication rates, and yet are twice as likely to die when compared to the global average. Approximately one in five surgical patients in Africa develops a postoperative complication, and one in ten of these patients will die. It is likely that many of these deaths are preventable. This large prospective cohort of surgery in 247 hospitals in 25 African countries, has revealed the limited workforce resources to provide safe surgical treatment. While it is imperative to increase access to surgery for the people of Africa, it is essential that that these surgical treatments are safe and effective.[27] Importantly, 95% of deaths occur in the postoperative period, suggesting that many lives could be saved by effective surveillance for physiological deterioration amongst patients who have developed complications and addressing the resources necessary to achieve this objective. Surgical outcomes will remain poor in Africa[15] until this problem is addressed.

Interpretation

Our results indicate that postoperative mortality following surgery is significantly higher in Africa, when compared to other international cohorts, despite a lower patient risk profile and lower postoperative complication rates.[9] Improving the quality of surgery is a function of structures, processes and outcomes as defined by the Lancet Commission on Global Surgery.[4] Our results provide important data on some of the processes and outcomes which need to be addressed in Africa. The great majority of these deaths occur on the days following surgery, and it seems likely that many are preventable. There are few published reports of postoperative outcomes in Africa, but our interpretation is consistent with the findings of a number of smaller epidemiological studies exploring postoperative mortality in African countries, with described mortality rates which were similar to,[14,28] or higher than those in the current study.[29,30] In a recent global study of mortality following emergency abdominal surgery, the majority of deaths also occurred more than 24 hours surgery.[14] Our observations are also consistent with reports of intraoperative and/or anaesthetic related mortality rates in low-income countries.[15,31] The findings of the current and previous work may be partly explained by the limited workforce resources, and poor early warning systems to detect the physiological deterioration of the patients who have developed complications.[32] The median number of 0·7 specialists (a combined total of surgeons, obstetricians and anaesthesiologists) per 100,000 population in this study, is well below the inflection point of 20 to 40 specialists per 100,000 thought necessary to decrease perioperative mortality.[4] Furthermore, there are fewer hospital, and critical care bed resources than recently reported at the global level.[9] Consequently, mortality following perioperative complications is significantly greater in Africa. The problem of unrecognised postoperative physiological deterioration on the surgical ward has been well described.[32] Interventions such as early warning scores, critical care outreach, medical emergency

teams, and critical care skills training for junior surgeons, are now standard in most high-income countries. 'Failure to rescue' and similar metrics have been successfully used to support data driven quality improvement projects.[33] Our findings suggest that the drivers of perioperative death may be broadly consistent across Africa, although further prospective audit is required to understand the site-specific drivers in individual hospitals, and countries. Recent work has demonstrated the feasibility of surgical outcomes audit in low-income countries.[28,34] A pragmatic continent-wide quality improvement programme may improve the allocation of resources towards the postoperative surveillance of patients most at risk. A simple surgical risk calculator may facilitate this approach.

Strengths and limitations

To our knowledge, this is the most comprehensive evaluation of surgical workforce density and patient outcomes following surgery conducted so far in Africa. Although, our study was not designed to inform detailed healthcare policy decisions in individual countries, the data are likely to have a significant impact throughout Africa. It seems likely that the drivers of morbidity and mortality are similar across these countries. Some of the country level data presented may provide the outcomes information required to power future country-specific studies of postoperative morbidity and mortality. Assuming a mortality rate of 2% and a 18% postoperative complication rate, an individual country-level surgical outcomes audit would require a 3000 patient sample to provide a reliable mortality estimate with a 95% confidence interval of 1%, and a 1400 patient sample to provide reliable complication rate with a 95% confidence interval of 4%. We used a simple data set consisting primarily of categorical variables to minimise the amount of missing data. Patient-level variables were selected on the basis that they were objective, routinely collected for clinical reasons, could be accurately transcribed with a low rate of missing data, and would be relevant to a risk adjustment model which included a variety of surgical procedures. National co-ordinators confirmed the face validity of their raw data prior to analysis.

The study also has some weaknesses. The 7-day cohort design was chosen as a pragmatic approach to tackling the paucity of epidemiological data describing this population. However, care should be taken in applying our findings in individual hospitals and countries. Variation in factors such as seasonal weather, industrial action, available healthcare workforce, armed conflict, surgical workload, and the healthcare seeking behaviour of patients, may all influence our results. Furthermore, these factors may also affect direct comparisons of surgical outcomes with high income countries. Fourteen countries did not provide per-protocol data samples, which may compromise the generalizability to these countries. However, it is possible that those hospitals unable to meet our protocol requirements face even greater difficulties in ensuring good patient outcomes. Indeed, more than half the countries in our study could not fulfil the protocol requirements for an included sample, and in hindsight these rules were inappropriately strict. Whilst 25 African countries participated, this was fewer than half of the countries in Africa, and a number of low-income countries did not

take part. Generalization to those unrepresented countries must be cautious, although it is possible that they too may have particular difficulties in delivering good surgical outcomes. Nearly half of the hospitals included in this study were university affiliated, and it is possible that our findings may underestimate poor patient outcomes reflected in smaller, more remote hospitals. We defined complications according to published criteria, also used in the ISOS study.[9] These definitions were developed in high-income countries, and it is possible that some complications were under-reported due to limited access to diagnostic tests, for example in the case of myocardial infarction. Meanwhile the assessment of some other complications can be subjective, in particular surgical site infection. Whilst few of our investigators were experienced researchers, it was beyond of the scope of this project to train them in a standard approach to assessing individual complications. This may have resulted in variability between hospitals. It is important to note that our primary focus was on all complications, rather than a specific individual complication. We carefully replicated the design of the previous ISOS study to allow comparison with the current global standard, but it should be noted that this comparison was not fully contemporaneous as these data were collected in 2014 whilst ASOS was conducted in 2016.

Conclusions

Surgical patients in Africa are younger, with a lower risk profile and low complication rates, but twice as likely to die when compared to the global average. Most deaths occur after surgery suggesting a need to improve the safety through postoperative surveillance for deteriorating patients on the ward. Contributory factors include limited numbers of specialists, poor hospital infrastructure, and low procedural volumes. The Lancet Commission on Global Surgery advocates improving access to safe, accessible and affordable surgical care. This study highlights the importance of effective perioperative care to achieving this objective in Africa. A pragmatic continent-wide quality improvement programme, including prospective audit, may reduce the number of preventable deaths following surgery in Africa.

Contributors

All authors were involved in the design and conduct of the study. Data collection and collation was done by the ASOS local investigators. The data analysis was conducted by BMB, TME and YLM. The first draft of the paper was written by BMB. The paper was redrafted by BMB following critical review by all authors.

Conflicts of interest

RP has received research grants from Edwards Lifesciences, Nestle Health Sciences and Intersurgical, has given lectures and/or performed consultancy work for Nestle Health Sciences, Medtronic, Edwards Lifesciences, BBraun and Glaxo Smithkline, and is a member of the associate editorial board of the British Journal of Anaesthesia. The authors declare that they have no conflict of interest.

Funding

The study was funded by a self-initiated Medical Research Council of South Africa grant awarded to BMB. The study website was maintained by the Safe Surgery South Africa (SSSA). They had no role in the study design, data acquisition, data analysis or writing up of the paper.

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Necessary additional data

Click here to download Necessary additional data: 2. ASOS Investigator List Lancet submission.docx

Table

Table 1· Description of the African Surgical Outcomes Study (ASOS) patient cohort.

	All patients (n=11422)	Patients with complications (n=1977)	Patients with no complications (n=8908)	Patients who died (n=239)	Patients who survived (n=10954)
Age (years)	38·5 (16·1) 34·0 (24·0-48·0)	40·7 (17·5) 36·0 (27·0-53·0)	38·0 (15·8) 33·0 (26·0-47·0)	49·5 (19·1) 51·0 (32·0-64·0)	38·3 (16·0) 34·0 (26·0-47·0)
Male	3833/11418 (33·6%)	819/1977 (41·4%)	2832/8908 (31·8%)	121/239 (50·6%)	3656/10953 (33·4%)
Current smoker	1520/11367 (16·8%)	315/1972 (16·0%)	1351/8881 (15·2%)	38/235 (16·2%)	1688/10924 (15·5%)
ASA category					
1	5713/11352 (50·3%)	781/1962 (39·8%)	4675/8887 (52·6%)	45239 (18·8%)	5552/10899 (50·9%)
2	4199/11352 (37·0%)	705/1962 (35·9%)	3309/8887 (37·2%)	62/239 (25·9%)	4050/10899 (37·2%)
3	1197/11352 (10·5%)	354/1962 (18·0%)	804/8887 (9·0%)	79/239 (33·1%)	1111/10899 (10·2%)
4	234/11352 (2·1%)	117/1962 (6·0%)	96/8887 (1·1%)	47/239 (19·7%)	184/10899 (1·7%)
5	9/11352 (0·1%)	5/1962 (0·3%)	3/8887 (0%)	6/239 (2·5%)	2/10899 (0%)
Grade of surgery					
Minor	2459/11341 (21·7%)	277/1972 (14·0%)	2064/8888 (23·2%)	28/238 (11·8%)	2392/10920 (21·9%)
Intermediate	5487/11341 (48·4%)	852/1972 (48·5%)	4415/8888 (49·7%)	96/238 (40·3%)	5322/10920 (48·7%)
Major	3395/11341 (29·7%)	843/1972 (42·7%)	2409/8888 (27·1%)	114/238 (47·9%)	3206/10920 (29·4%)
Urgency of surgery					
Elective	4874/11378 (42·8%)	624/1970 (31·7%)	4034/8896 (45·3%)	48/239 (20·1%)	4744/10928 (43·4%)
Urgent	2700/11378 (23·7%)	519/1970 (26·3%)	2036/8896 (22·9%)	77/239 (32·2%)	2562/10928 (23·4%)
Emergency	3804/11378 (33·4%)	827/1970 (42·0%)	2826/8896 (31·8%)	114/239 (47·7%)	3622/10928 (33·1%)
Surgical speciality					
Orthopaedic	1770/11393 (15·5%)	292/1977 (14·8%)	1372/8902 (15·4%)	27/239 (11·3%)	1710/11179 (15·6%)
Breast	229/11393 (2·0%)	31/1977 (1·6%)	192/8902 (2·2%)	2/239 (0·8%)	227/11179 (2·1%)
Obstetrics	3792/11393 (33·3%)	531/1977 (26·9%)	3074/8902 (34·5%)	20/239 (8·4%)	3664/11179 (33·5%)
Gynaecology	1305/11393 (11·5%)	153/1977 (7·7%)	1102/8902 (12·4%)	7/239 (2·9%)	1285/11179 (11·7%)
Upper GIT	301/11393 (2·6%)	102/1977 (5·2%)	191/8902 (2·1%)	29/239 (12·1%)	268/11179 (2·4%)
Lower GIT	940/11393 (8·3%)	228/1977 (11·5%)	670/8902 (7·5%)	46/239 (19·2%)	872/11179 (8·0%)
Hepatobiliary	172/11393 (1·5%)	28/1977 (1·4%)	139/8902 (1·6%)	4/239 (1·7%)	168/11179 (1·5%)
Urology and kidney	560/11393 (4·9%)	108/1977 (5·5%)	430/8902 (4·8%)	13/239 (5·4%)	541/11179 (4·9%)
Vascular	237/11393 (2·1%)	72/1977 (3·6%)	153/8902 (1·7%)	16/239 (6·7%)	219/11179 (2·0%)
Head and neck	453/11393 (4·0%)	68/1977 (3·4%)	356/8902 (4·0%)	13/239 (5·4%)	431/11179 (3·9%)
Cardiac surgery	58/11393 (0·5%)	21/1977 (1·1%)	35/8902 (0·4%)	6/239 (2·5%)	52/11179 (0·5%)
Thoracic (lung and other)	130/11393 (1·1%)	37/1977 (1·9%)	92/8902 (1·0%)	8/239 (3·3%)	122/11179 (1·1%)
Thoracic (gut)	23/11393 (0·2%)	9/1977 (0·5%)	14/8902 (0·2%)	2/239 (0·8%)	21/11179 (0·2%)
Neurosurgery	253/11393 (2·2%)	85/1977 (4·3%)	156/8902 (1·8%)	21/239 (8·8%)	230/11179 (2·1%)
Other	555/11393 (4·9%)	79/1977 (4·0%)	471/8902 (5·3%)	11/239 (4·6%)	541/11179 (4·9%)
Surgical checklist	6183/10836 (57·1%)	1082/1971 (54·9%)	5101/8865 (57·5%)	145/239 (60·7%)	6188/10894 (56·8%)
Comorbidity					
Coronary artery disease	178/11422 (1·6%)	53/1977 (2·7%)	119/8908 (1·3%)	11/239 (4·6%)	166/10954 (1·5%)
Congestive heart failure	92/11422 (0·8%)	30/1977 (1·5%)	58/8908 (0·7%)	11/239 (4·6%)	80/10954 (0·7%)
Diabetes mellitus	776/11422 (6·8%)	201/1977 (10·20%)	547/8908 (6·1%)	46/239 (19·2%)	722/10954 (6·6%)
Cirrhosis	12/11422 (0·1%)	5/1977 (0·3%)	5/8908 (0·1%)	0/239 (0%)	11/10954 (0·1%)
Metastatic cancer	142/11422 (1·2%)	32/1977 (1·6%)	103/8908 (1·2%)	11/239 (4·6%)	129/10954 (1·2%)

Hypertension	1863/11422 (16·3%)	377/1977 (19·1%)	1406/8908 (15·8%)	77/239 (32·2%)	1767/10954 (16·1%)
Stroke or Transient ischaemic attack	91/11422 (0·8%)	36/1977 (1·8%)	48/8908 (0·5%)	8/239 (3·3%)	82/10954 (0·7%)
COPD/Asthma	375/11422 (3·3%)	75/1977 (3·8%)	274/8908 (3·1%)	13/239 (5·4%)	357/10954 (3·3%)
HIV positive/AIDS	1253/11422 (11·0%)	222/1977 (11·2%)	986/8908 (11·1%)	18/239 (7·5%)	1224/10954 (11·2%)
Chronic renal disease	171/11422 (1·5%)	46/1977 (2·3%)	111/8908 (1·2%)	14/239 (5·9%)	154/10954 (1·4%)

Data are mean (SD), median (25^{th}/75^{th} percentile) or n (proportion). Denominators vary with the completeness of the data. Odds ratios were constructed for in-hospital complications and mortality with univariate binary logistic regression analysis. The denominator for each group is shown. CI= confidence interval. ASA=American Society of Anesthesiologists. GIT= gastrointestinal. COPD=chronic obstructive pulmonary disease. HIV=human immunodeficiency virus. AIDS=acquired immunodeficiency syndrome.

Table 2. Postoperative outcomes in the African Surgical Outcomes Study. Data presented as n (%).

Outcome	Number of patients	Patients admitted to critical care immediately after surgery	Patients not admitted to critical care immediately after surgery
All surgeries			
Mortality	239/11193 (2·1)	108/1198 (9·0)	130/9960 (1·3)
Complications	1977/10885 (18·2)	495/1971 (25·1)	1476/9705 (15·2)
Critical care admission to treat complications	321/1972 (16·3)	255/493* (51·7)	64/1473† (4·3)
Death following a postoperative complication	188/1970 (9·5)	96/493* (19·5)	92/1472† (6·3)
Elective surgery only			
Mortality	48/4792 (1·0)	12/376 (3·2)	35/4403 (0·8)
Complications	624/4658 (13·4)	140/367 (38·1)	482/4282 (11·3)
Critical care admission to treat complications	86/622 (13·8)	68/140* (48·6)	17/480† (3·5)
Death following a postoperative complication	30/620 (4·8)	10/139* (7·2)	20/480† (4·2)

Denominators vary with the completeness of the data. *total number admitted to critical care immediately following surgery; †total number not admitted to critical care immediately after surgery

Table

Table 3. Postoperative complications in the African Surgical Outcomes Study (ASOS). Data are presented as n (%).

Complications	Number of patients	Mild	Moderate	Severe	Mortality for all patients that developed complications	Mortality for elective surgical patients that developed complications
Infectious complications						
Superficial surgical site	10968	402 (3·5)	303 (2·7)	82 (0·7)	41/787 (5·21)	5/245 (2·0)
Deep surgical site	10969	77 (0·7)	141 (1·2)	110 (1·0)	43/328 (13·1)	3/78 (3·8)
Body cavity	10968	25 (0·2)	55 (0·5)	45 (0·4)	28/125 (22·4)	1/21 (4·8)
Pneumonia	10968	51 (0·5)	85 (1·2)	49 (0·4)	56/185 (30·3)	5/50 (10·0)
Urinary tract	10967	64 (0·6)	29 (0·3)	19 (0·2)	20/112 (17·9)	2/38 (6·3)
Bloodstream	10970	27 (0·2)	50 (0·5)	64 (0·6)	58/141 (41·1)	6/32 (18·8)
Total number of patients with infectious complications					112/1156 (9·7)	12/354 (3·4)
Cardiovascular complications						
Myocardial infarction	10969	7 (0·1)	1 (0·0)	3 (0·0)	3/11 (27·3)	0/2 (0·0)
Arrhythmia	10969	16 (0·1)	14 (0·1)	10 (0·1)	11/40 (27·5)	1/14 (7·1)
Pulmonary oedema	10969	17 (0·1)	13 (0·1)	8 (0·1)	17/38 (44·7)	1/7 (14·3)
Pulmonary embolism	10969	3 (0·0)	1 (0·0)	11 (0·1)	11/15 (73·3)	5/8 (62·5)
Stroke	10921	6 (0·1)	6 (0·1)	8 (0·1)	6/20 (30·0)	1/7 (14·3)
Cardiac arrest	10945			113 (1·0)	101/113 (89·4)	13/19 (68·4)
Total number of patients with cardiovascular complications					110/190 (57·9)	15/48 (31·3)
Other complications						
Gastrointestinal bleed	10966	20 (0·2)	12 (0·1)	7 (0·1)	13/39 (33·3)	1/11 (9·1)
Acute kidney injury	10967	50 (0·4)	54 (0·5)	42 (0·4)	51/146 (34·9)	4/31 (12·9)
Postoperative bleed	10968	98 (0·9)	404 (3·5)	59 (0·5)	39/561 (7·0)	5/159 (3·1)
ARDS	10966	14 (0·1)	19 (0·2)	19 (0·2)	26/52 (50·0)	4/14 (28·6)
Anastomotic leak	10961	9 (0·1)	14 (0·1)	23 (0·2)	16/46 (34·8)	3/19 (15·8)
All others	10936	151 (1·3)	147 (1·3)	83 (0·7)	40/381 (10·5)	5/131 (3·8)
Total number of patients with other complications					112/1044 (10·7)	14/314 (4·5)
Total number of patients with complications					188/1970 (9·5)	30/620 (4·8)

Denominators vary with the completeness of the data. ARDS acute respiratory distress syndrome

Table

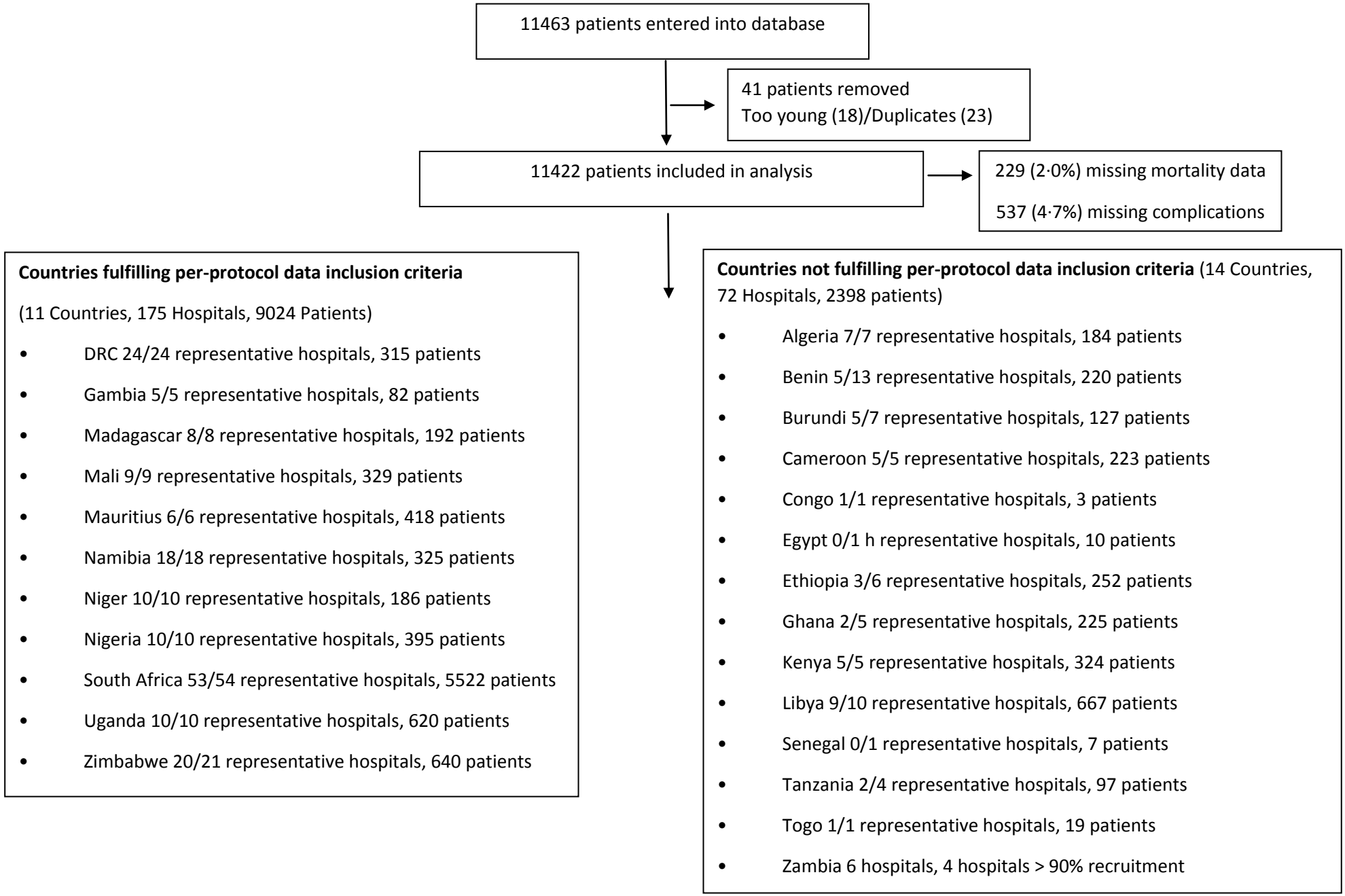
Table 4. The association between the primary indication for surgery and postoperative complications and in-hospital mortality. Data presented as n (%)

	All patients (n=10842)	Complications (n=1973)	No complications (n=8869)	Odds ratio (95% CI)	P value	Died (n=238)	Survived (n=10876)	Odds ratio (95% CI)	P value
Non-communicable disease	4577 (42·2%)	736 (37·3%)	4577 (42·2%)	Reference		96 (40·3%)	4607 (42·4%)	Reference	
Acute infection	1380 (12·7%)	398 (20·2%)	982 (12·7%)	2·12 (1·84–2·44)	<0·0001	63 (26·5%)	1352 (12·4%)	2·24 (1·62 - 3·09)	<0·0001
Trauma	1929 (17·8%)	405 (20·5%)	1524 (17·8%)	1·39 (1·21–1·59)	<0·0001	61 (25·6%)	1947 (17·9%)	1·50 (1·09 – 2·08)	0·0140
Caesarean section	2956 (27·3%)	434 (22·0%)	2522 (28·4%)	0·90 (0·79–1·02)	0·10	18 (7·6%)	2970 (27·3%)	0·29 (0·18 – 0·48)	<0·0001

Figure

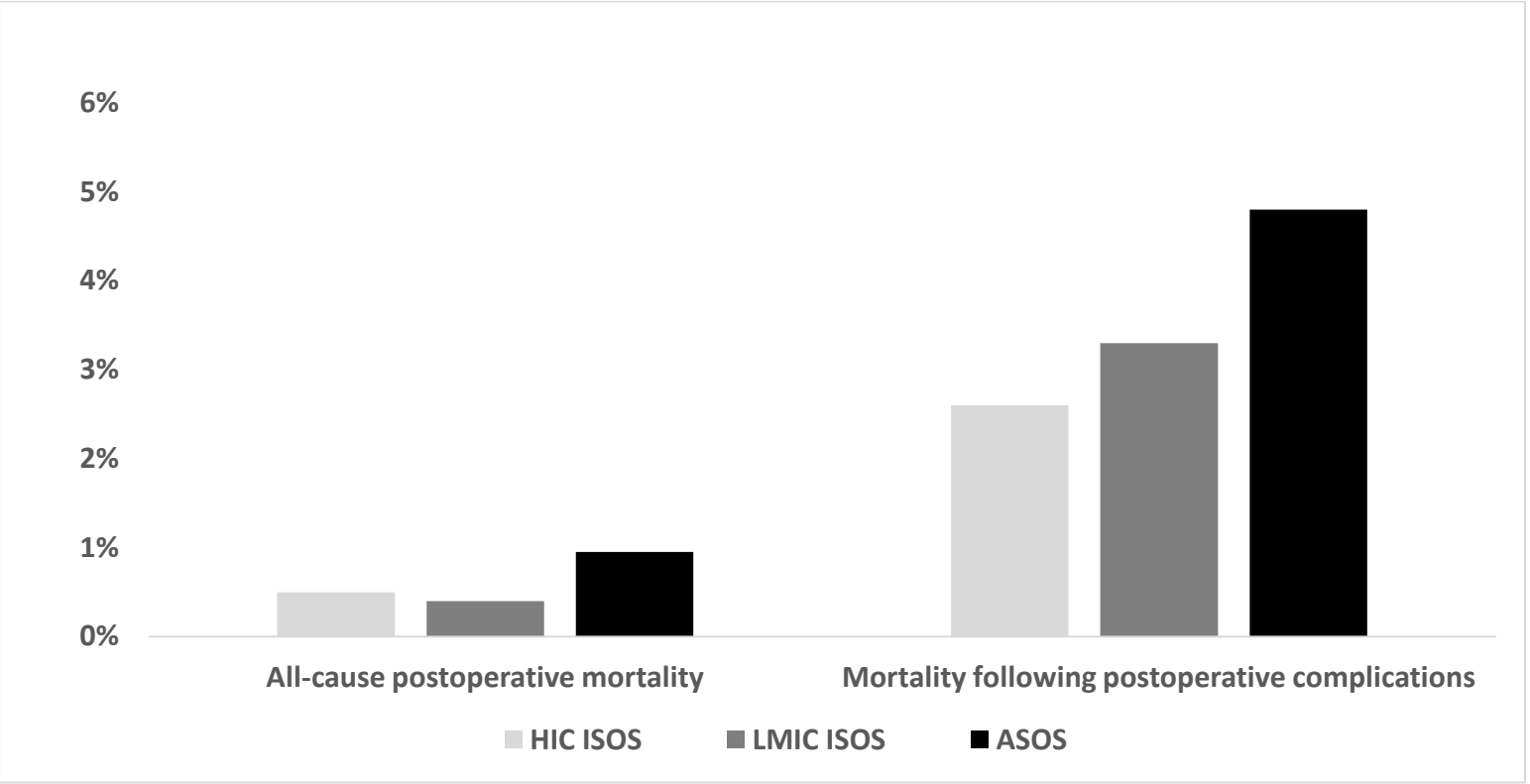
Figure

Figure 2. African Surgical Outcomes Study (ASOS) country, hospital and patient recruitment



Figure

Figure 3. Surgical mortality following elective surgery in high-income, low-middle income, and African countries



ISOS International Surgical Outcomes Study, ASOS African Surgical Outcomes Study, HIC high income countries, LMIC low-middle income countries

Table

Supplementary Table 1. The country-specific reported mortality, postoperative complications, critical care admission and duration of hospital stay

Country	Patients	In-hospital mortality	% In-hospital mortality (95% CI)*	Postoperative complications	% Postoperative complications (95% CI)	Critical care admission	% Critical care admission (95% CI) *	Median days in hospital (25^{th}/75^{th} centile)
Algeria	184 (1·6%)	7/184	3·8% (1·0 – 6·6)	58/183	31·7% (25·0-38·4)	15/184	8·2% (4·2-12·1)	5 (3-7)
Benin	220 (1·9%)	2/173	1·2% (0-2·7)	24/132	18·2% (11·6-24·8)	42/157	26·8% (19·8-33·7)	5 (4-8)
Burundi	127 (1·1%)	1/74	1·4% (0-4·0)	14/74	18·9% (10·0-27·8)	0/74		4 (3-7)
Cameroon	223 (2·0%)	3/223	1·3% (0-2·9)	29/221	13·1% (8·7-17·6)	2/223	0·9% (0-2·1)	3 (2-5)
Congo	3 (0%)	0/3		0/3		0/3		3 (2-4)
DRC	315 (2·8%)	12/315	3·8% (1·7 – 5·9)	64/314	20·4% (15·9-24·8)	17/315	5·4% (2·9-7·9)	8 (5-12)
Egypt	10 (0·1%)	0/9		8/10	80% (55·2-100)	0/10		2 (2-4)
Ethiopia	252 (2·2%)	6/247	2·4% (0·5-4·3)	55/232	23·7% (18·2-29·2)	7/250	2·8% (0·8-4·8)	3 (2-7)
Gambia	82 (0·7%)	3/82	3·7% (0-7·7)	20/82	24·4% (15·1-33·7)	3/82	3·7% (0-7·7)	4 (3-7)
Ghana	225 (2·0%)	2/146	1·4% (0·5-3·3)	26/147	17·7% (11·5-23·9)	2/147	1·4% (0-3·2)	5 (3-7)
Kenya	324 (2·8%)	5/324	1·5% (0·2-2·9)	80/321	24·9% (20·2-29·7)	10/323	3·1% (1·2-5·0)	4 (3-8)
Libya	667 (5·8%)	5/664	0·8% (0·1-1·4)	126/663	19·0% (16·0-22·0)	35/663	5·3% (3·6-7·0)	2 (1-3)
Madagascar	192 (1·7%)	2/192	1·0% (0-2·5)	42/192	21·9% (16·0-27·7)	18/192	9·4% (5·3-13·5)	5 (3-6)
Mali	329 (2·9%)	11/329	3·3% (1·4-5·3)	72/323	22·3% (17·8-26·8)	12/328	3·7% (1·6-5·7)	4 (3-6)
Mauritius	418 (3·7%)	8/418	1·9% (0·6-3·2)	52/417	12·5% (9·3-15·6)	16/418	3·8% (2·0-5·7)	3 (1-5)
Namibia	325 (2·8%)	12/325	3·7% (1·6-5·7)	59/323	18·3% (14·1-22·5)	14/325	4·3% (2·1-6· 5)	4 (2-6)
Niger	186 (1·6%)	2/186	1·1% (0-2·6)	71/186	38·2% (31·2-45·2)	27/186	14·5% (0·9-19·6)	5 (3-8)
Nigeria	395 (3·5%)	8/392	2·0% (0·6-3·4)	67/379	17·7% (13·8-21·5)	15/395	3·8% (1·9-5·7)	6 (4-9)
Senegal	7 (0·1%)	1/7	14·3% (0-40·2)	3/7	42·9% (6·2-79·5)	1/7	14·3% (0-40·2)	5 (2-6)
South Africa	5522 (48·3%)	132/5492	2·4% (2·0-2·8)	810/5274	15·4% (14·4-16·3)	220/5308	4·1% (3·6-4·7)	3 (2-5)
Tanzania	97 (0·8%)	0/97		17/96	17·7% (10·1-25·3)	21/97	21·6% (13·4-28·8)	3 (2-3)
Togo	19 (0·2%)	0/18		0/19		0/11		10 (7-19)
Uganda	620 (5·4%)	7/619	1·1% (0·3-2·0)	195/617	31·6% (27·9-35·3)	7/619	1·1% (0·3-2·0)	3 (3-5)
Zambia	40 (0·4%)	2/34	5·9% (0-13·8)	12/34	35·3% (19·2-51·4)	3/34	8·8% (0-18·4)	4 (3-6)
Zimbabwe	640 (5·6%)	8/640	1·3% (0·4-2·1)	72/635	11·3% (8·9-13·8)	24/640	3·8% (2·3-5·2)	3 (3-4)
All	11422	239/11193	2·1% (1·9-2·4)	1977/10885	18·2% (17·4-18·9)	511/10991	4·6% (4·3-5·0)	3 (2-6)

Denominators vary with the completeness of the data. DRC Democratic Republic of the Congo; CI confidence interval

*The country specific crude mortality rates and complication rates are particularly unstable as the study was not powered to accurately determine the country specific mortality and complication rates. A country sample size of at least 3000 patients would be required for a relatively stable estimate of mortality and 1400 patients for a relatively stable estimate of postoperative complications.

Table

Supplementary Table 2. Multivariable model of in-hospital mortality per-protocol analysis.

	Odds ratio (OR)	95% confidence interval (CI)	P-value
Intercept	0·002	0·000-0·046	<0·0001
Patient factors			
Age spline 1	0·990	0·869-1·129	0·89
Age spline 2	1·125	0·133-9·503	0·91
Age spline 3	0·985	0·005-185·709	1·00
Age spline 4	0·773	0·017-34·282	0·89
ASA 1	Reference		
ASA 2	1·438	0·910-2·273	0·12
ASA 3	3·627	2·269-5·799	<0·0001
ASA 4 or 5	10·153	5·986-17·222	<0·0001
Surgical factors			
Elective surgery	Reference		
Urgent surgery	3·296	2·155-5·041	<0·0001
Emergent surgery	4·397	2·864-6·752	<0·0001
Minor surgery	Reference		
Intermediate surgery	1·699	1·038-2·782	0·04
Major surgery	2·595	1·536-4·385	0·0004
Cardiothoracic and vascular surgery	1·773	0·983-3·197	0·06
Ear nose and throat	2·279	1·062-4·892	0·03
Gastrointestinal and hepatobiliary	2·599	1·572-4·296	0·0002
Gynaecology and obstetrics	0·329	0·170-0·634	0·0009
Neurosurgery	2·794	1·378-5·663	0·0044
Other	1·133	0·508-2·528	0·76
Plastics and breast	1·576	0·773-3·212	0·21
Urology	1·684	0·803-3·535	0·17
Countries			
A	2·006	1·029-3·913	0·04

B	1·080	0·301-3·875	0·91
C	0·387	0·090-1·665	0·20
D	1·892	0·952-3·761	0·07
E	1·062	0·491-2·295	0·88
F	2·525	1·292-4·933	0·0067
G	0·407	0·094-1·765	0·23
H	0·667	0·307-1·446	0·31
I	0·821	0·361-1·867	0·64
J	0·614	0·270-1·397	0·25

ASA American Society of Anesthesiologists; A-J anonymised countries

Supplementary Table 3. Comparison between the elective surgery patients of the African Surgical Outcomes Study (per-protocol, representative sample) and the International Surgical Outcomes Study

	ASOS (n=3868)	ISOS (n=44814)
Risk factors		
Age	44·6 (17·0)	55·3 (17·1)
ASA 1	1737 (44·9)	11 227 (25·1)
Minor surgery	1140 (29·5)	672 (8·0)
Outcomes		
Mortality	42 (1·1)	207 (0·5)
Complications	468 (12·1)	7508 (16·8)
Mortality following complications	26/468 (5·6)	207/7508 (2·8)

Data are mean (SD) or n (proportion). ASOS= African Surgical Outcomes Study. ISOS= International Surgical Outcomes Study. ASA=American Society of Anesthesiologists.

Table

Supplementary Table 4. Hospital facilities and resources data (n=166) of the per-protocol representative country sample analysis. Data presented as n (%) or median [25th/75th centile]

Hospital facilities and resources	n (%) or median [25th/75th centile]
Population served by the hospital	881 500 [200 000-2000 000]
University affiliated hospital	70/162 (43·2)
Government funding/ private funding/ government and private funding	129 (77·7) / 26 (15·7) / 11 (6·6)
Type of hospital	
Primary-level hospital	36 (21·7)
Secondary-level hospital	59 (35·5)
Tertiary-level hospital	71 (42·3)
Hospital resources	
Hospital beds	300 [135-525]
Operating rooms	4 [2-7]
Critical care beds allowing invasive ventilation	3 [0-6]
Full time specialist surgeons	3 [1-7]
Full time specialist anaesthesiologists	1 [1-5]
Full time specialist obstetricians	2 [0-5]
Combined number of specialist surgeons, anaesthesiologists and obstetricians	7 [2-16]
Combined number of specialist surgeons, anaesthesiologists and obstetricians/100,000 population	0·7 [0·2-1·9]

Table

Supplementary Table 5. Description of the per-protocol representative sample of the African Surgical Outcomes Study (ASOS) patient cohort.

	All patients (n=9024)	Patients with complications (n=1525)	Patients with no complications (n=7218)	Patients who died (n=205)	Patients who survived (n=8785)
Age (years)	39·0 (16·4) 34·0 (26·0-49·0)	41·0 (17·5) 36·0 (27·0-53·0)	38·5 (16·1) 33·0 (26·0-48·0)	50·7 (19·2) 52·0 (33·5-65·0)	38·7 (16·2) 34·0 (26·0-48·0)
Male	3025/9024 (33·5%)	617/1525 (40·5%)	2278/7218 (31·6%)	103/205 (50·2%)	2909/8785 (33·1%)
Current smoker	1520/8995 (16·8%)	252/1521 (16·6%)	1204/7195 (16·7%)	33/202 (16·9%)	1481/8760 (16·95%)
ASA category					
1	4196/9016 (46·5%)	534/1523 (35·1%)	3543/7214 (49·1%)	35/205 (17·1%)	4145/8778 (47·2%)
2	3515/9016 (39·0%)	575/1523 (37·8%)	2834/7214 (39·3%)	52/205 (25·4%)	3452/8778 (39·3%)
3	1084/9016 (12·0%)	306/1523 (20·1%)	744/7214 (10·3%)	70/205 (34·1%)	1010/8778 (11·5%)
4	213/9016 (2·4%)	103/1523 (6·8%)	91/7214 (1·3%)	42/205 (20·5%)	170/8778 (1·9%)
5	8/9016 (0·1%)	5/1523 (0·3%)	2/7214 (0%)	6/205 (2·9%)	1/8778 (0%)
Grade of surgery					
Minor	2105/9010 (23·3%)	228/1521 (15·0%)	1789/7209 (24·8%)	23/205 (11·2%)	2065/8772 (23·5%)
Intermediate	4536/9010 (50·3%)	654/1521 (43·0%)	3758/7209 (52·1%)	86/205 (42·0%)	4442/8772 (50·6%)
Major	2369/9010 (26·3%)	639/1521 (42·0%)	1662/7209 (23·1%)	96/205 (46·8%)	2265/8772 (25·8%)
Urgency of surgery					
Elective	3868/9014 (42·9%)	468/1520 (30·8%)	3271/7213 (45·3%)	42/205 (20·5%)	3810/8775 (43·4%)
Urgent	2116/9014 (23·4%)	401/1520 (26·4%)	1639/7213 (22·7%)	66/205 (32·2%)	2040/8775 (23·2%)
Emergency	3030/9014 (33·6%)	651/1520 (42·8%)	2303/7213 (31·9%)	97/205 (47·3%)	2925/8775 (33·3%)
Surgical speciality					
Orthopaedic	1472/9022 (16·3%)	235/1525 (15·4%)	1372/7216 (15·5%)	26/205 (12·7%)	1433/8783 (16·3%)
Breast	187/9022 (2·1%)	20/1525 (1·3%)	162/7216 (2·2%)	2/205 (1·0%)	185/8783 (2·1%)
Obstetrics	2879/9022 (31·9%)	395/1525 (25·9%)	2433/7216 (33·7%)	15/205 (7·3%)	2857/8783 (32·5%)
Gynaecology	1118/9022 (12·4%)	133/1525 (8·7%)	954/7216 (13·2%)	7/205 (3·4%)	1110/8783 (12·6%)
Upper GIT	222/9022 (2·5%)	73/1525 (4·8%)	145/7216 (2·0%)	25/205 (12·2%)	197/8783 (2·2%)
Lower GIT	723/9022 (8·0%)	174/1525 (11·4%)	528/7216 (7·3%)	39/205 (19·0%)	682/8783 (7·8%)
Hepatobiliary	120/9022 (1·3%)	24/1525 (1·6%)	95/7216 (1·3%)	4/205 (2·0%)	116/8783 (1·3%)
Urology and kidney	477/9022 (5·3%)	87/1525 (5·7%)	373/7216 (5·2%)	12/205 (5·9%)	463/8783 (5·3%)
Vascular	190/9022 (2·1%)	57/1525 (3·7%)	124/7216 (1·7%)	15/205 (7·3%)	175/8783 (2·0%)
Head and neck	326/9022 (3·6%)	56/1525 (3·7%)	248/7216 (3·4%)	11/205 (5·4%)	312/8783 (3·6%)
Plastics/ Cutaneous	469/9022 (5·2%)	91/1525 (6·0%)	358/7216 (5·0%)	11/205 (5·4%)	453/8783 (5·2%)
Cardiac surgery	54/9022 (0·6%)	18/1525 (1·2%)	34/7216 (0·5%)	5/205 (2·4%)	49/8783 (0·6%)
Thoracic (lung and other)	113/9022 (1·3%)	30/1525 (2·0%)	82/7216 (1·1%)	6/205 (2·9%)	107/8783 (1·2%)
Thoracic (gut)	18/9022 (0·2%)	6/1525 (0·4%)	12/7216 (0·2%)	2/205 (1·0%)	16/8783 (0·2%)
Neurosurgery	186/9022 (2·1%)	66/1525 (4·3%)	116/7216 (1·6%)	16/205 (7·8%)	170/8783 (1·9%)
Other	468/9022 (5·2%)	66/1525 (4·3%)	399/7216 (5·5%)	9/205 (4·4%)	458/8783 (5·2%)
Surgical checklist	5096/8730 (58·4%)	815/1522 (53·5%)	4281/7208 (59·4%)	124/205 (60·5%)	5099/8771 (58·1%)
Preoperative comorbidity					
Coronary artery disease	154/9024 (1·7%)	40/7218 (2·6%)	108/1525 (1·5%)	9/205 (4·4%)	144/8785 (1·6%)
Congestive heart failure	76/9024 (0·8%)	21/7218 (1·4%)	52/1525 (0·7%)	9/205 (4·4%)	67/8785 (0·8%)
Diabetes mellitus	654/9024 (7·2%)	168/7218 (11·0%)	466/1525 (6·5%)	44/205 (21·5%)	609/8785 (6·9%)

Cirrhosis	7/9024 (0·1%)	1/7218 (0·1%)	5/1525 (0·1%)	0/205 (0%)	7/8785 (0·1%)
Metastatic cancer	123/9024 (1·4%)	27/7218 (1·8%)	91/1525 (1·3%)	11/205 (5·4%)	112/8785 (1·3%)
Hypertension	1662/9024 (18·4%)	319/7218 (20·9%)	1279/1525 (17·7%)	69/205 (33·7%)	1586/8785 (18·1%)
Stroke or Transient ischaemic attack	80/9024 (0·9%)	29/7218 (1·9%)	45/1525 (0·6%)	6/205 (2·9%)	74/8785 (0·8%)
COPD/Asthma	346/9024 (3·8%)	67/7218 (4·4%)	258/1525 (3·6%)	13/205 (6·3%)	331/8785 (3·8%)
HIV positive/AIDS	1211/9024 (13·4%)	211/7218 (13·8%)	962/1525 (13·3%)	17/205 (8·3%)	1188/8785 (13·5%)
Chronic renal disease	150/9024 (1·7%)	39/7218 (2·6%)	97/1525 (1·3%)	14/205 (6·8%)	133/8785 (1·5%)

Data are mean (SD), median (25^{th}/75^{th} percentile) or n (proportion). Denominators vary with the completeness of the data. Odds ratios were constructed for in-hospital complications and mortality with univariate binary logistic regression analysis. The denominator for each group is shown. CI= confidence interval. ASA=American Society of Anesthesiologists. GIT= gastrointestinal. COPD=chronic obstructive pulmonary disease. HIV=human immunodeficiency virus. AIDS=acquired immunodeficiency syndrome.

Table

Supplementary Table 6. Per-protocol representative sample of postoperative outcomes in the African Surgical Outcomes Study. Data presented as n (%).

Outcome	Number of patients	Patients admitted to critical care immediately after surgery	Patients not admitted to critical care immediately after surgery
All surgeries			
Mortality	205/8990 (2·3)	85/726 (11·7)	120/8251 (1·5)
Any complications	1525/8797 (17·3)	326/706 (46·2)	1196/8025 (14·9)
Critical care admission to treat complications	244/1523 (16·0)	190/326* (58·3)	53/1196† (4·4)
Death following a postoperative complication	156/1525 (10·2)	74/326* (22·7)	82/1196† (6·9)
Elective surgery only			
Mortality	42/3846 (1·1)	9/241 (3·7)	33/3605 (0·9)
Complications	467/3734 (12·5)	91/238 (38·2)	376/3496 (10·8)
Critical care admission to treat complications	91/467 (19·5)	50/91* (54·9)	14/376† (3·7)
Death following a postoperative complication	26/467 (5·6)	8/91* (8·8)	18/376† (4·8)

Denominators vary with the completeness of the data. *total number admitted to critical care immediately following surgery; †total number not admitted to critical care immediately after surgery

Table

Supplementary Table 7. Postoperative complications (per-protocol, representative sample analysis) in the African Surgical Outcomes Study (ASOS). Data are presented as n (%).

Complications	Number of patients	Mild	Moderate	Severe	Mortality for all patients that developed complications	Mortality for elective surgical patients that developed complications
Infectious complications						
Superficial surgical site	8796	287 (3.2)	240 (2.7)	60 (0.7)	29/687 (4.22)	5/182 (2.7)
Deep surgical site	8798	56 (0.6)	107 (1.2)	90 (1.0)	35/253 (13.8)	3/55 (5.5)
Body cavity	8797	22 (0.2)	48 (0.5)	43 (0.5)	23/113 (20.4)	1/19 (5.3)
Pneumonia	8797	34 (0.4)	69 (0.8)	42 (0.5)	36/185 (24.8)	5/34 (14.7)
Urinary tract	8797	49 (0.5)	23 (0.3)	17 (0.2)	17/112 (19.1)	2/29 (6.9)
Bloodstream	8797	19 (0.2)	39 (0.4)	52 (0.6)	44/110 (40.0)	5/18 (27.8)
Total number of patients with infectious complications					89/891 (10.0)	11/267 (4.1)
Cardiovascular complications						
Myocardial infarction	8797	7 (0.1)	1 (0.0)	3 (0.0)	3/11 (27.3)	0/2 (0.0)
Arrhythmia	8797	10 (0.1)	13 (0.1)	10 (0.1)	10/33 (30.3)	1/10 (10.0)
Pulmonary oedema	8797	14 (0.2)	12 (0.1)	8 (0.1)	16/34 (47.1)	1/5 (20.0)
Pulmonary embolism	8797	2 (0.0)	1 (0.0)	10 (0.1)	11/13 (84.6)	5/6 (83.3)
Stroke	8756	5 (0.1)	6 (0.1)	6 (0.1)	5/17 (29.4)	1/6 (16.7)
Cardiac arrest	8779			97 (1.1)	87/97 (89.7)	12/17 (70.6)
Total number of patients with cardiovascular complications					95/163 (58.3)	14/41 (34.1)
Other complications						
Gastrointestinal bleed	8797	18 (0.2)	7 (0.1)	7 (0.1)	12/32 (37.5)	1/7 (14.3)
Acute kidney injury	8797	34 (0.4)	39 (0.4)	37 (0.4)	43/110 (39.1)	4/15 (26.7)
Postoperative bleed	8797	82 (0.9)	297 (3.5)	46 (0.5)	32/425 (7.5)	4/112 (3.6)
ARDS	8797	10 (0.1)	16 (0.2)	14 (0.2)	20/40 (50.0)	3/7 (42.9)
Anastomotic leak	8795	7 (0.1)	7 (0.1)	20 (0.2)	13/34 (38.2)	3/11 (27.3)
All others	8791	118 (1.3)	111 (1.2)	72 (0.8)	34/301 (11.3)	5/100 (5.0)
Total number of patients with other complications					91/794 (11.5)	12/232 (5.2)
Total number of patients with complications					156/1525 (10.2)	26/468 (5.6)

Denominators vary with the completeness of the data. ARDS acute respiratory distress syndrome

Table

Supplementary Table 8. The association between the primary indication for surgery and postoperative complications and in-hospital mortality, per-protocol analysis. Data presented as n (%)

	All patients (n=8982)	Complications (n=1521)	No complications (n=7196)	Odds ratio (95% CI)	P value	Died (n=205)	Survived (n=8744)	Odds ratio (95% CI)	P value
Non-communicable disease	3709 (41·1%)	555 (36·5%)	3048 (42·4%)	Reference		80 (39·0%)	3616 (41·4%)	Reference	
Infective	1203 (13·3%)	334 (22·0%)	824 (11·5%)	2·23 (1·90 – 2·60)	<0·0001	56 (27·3%)	1138 (13·0%)	2·22 (1·57- 3·15)	<0·0001
Trauma	1631 (18·1%)	299 (19·7%)	1250 (17·4%)	1·31 (1·13 – 1·53)	0·0006	54 (26·3%)	1570 (18·0%)	1·56 (1·10 – 2·21)	0·01
Caesarean section	2439 (27·0%)	333 (21·9%)	2074 (28·8%)	0·88 (0·76 – 1·02)	0·09	15 (7·3%)	2420 (27·7%)	0·28 (0·16 – 0·49)	<0·0001

Table

Supplementary Table 9. The African regional level-specific reported mortality, postoperative complications, critical care admission and duration of hospital stay

Hospital	Patients	In-hospital mortality	% In-hospital mortality (95% CI)	Postoperative complications	% Postoperative complications (95% CI)	Critical care admission	% Critical care admission (95% CI)	Median days in hospital (25^{th}/75^{th} centile)
Central Africa	541 (4·7%)	15/541	2·8% (1·4-4·2)	93/538	17·3% (14·1-20·5)	19/541	3·5% (2·0-5·1)	5 (3-10)
Eastern Africa	1420 (12·4%)	19/1361	1·4% (0·8-2·1)	361/1340	26·9% (24·6-29·3)	45/1363	3·3% (2·4-4·3)	3 (3-5)
Northern Africa	861 (7·5%)	12/857	1·4% (0·6-2·2)	192/856	22·4% (19·6-25·2)	50/857	5·8% (4·3-7·4)	2 (1-4)
Southern Africa	6527 (57·1%)	154/6491	2·4% (2·0-2·7)	953/6266	15·2% (14·3-16·1)	261/6307	4·1% (3·6-4·6)	3 (2-5)
Western Africa	1463 (12·8%)	29/1333	2·2% (1·4-3·0)	284/1276	22·3% (20·0-24·5)	102/1313	7·8% (6·3-9·2)	5 (3-7)
Indian Ocean Islands	610 (5·3%)	10/610	1·6% (0·6-2·6)	94/609	15·4% (12·6-18·3)	34/610	5·6% (3·8-7·4)	3 (2-6)

Denominators vary with the completeness of the data. CI confidence interval

Table

Supplementary Table 10. The hospital level-specific reported mortality, postoperative complications, critical care admission and duration of hospital stay

Hospital	Patients	In-hospital mortality	% In-hospital mortality (95% CI)	Postoperative complications	% Postoperative complications (95% CI)	Critical care admission	% Critical care admission (95% CI)	Median days in hospital (25^{th}/75^{th} centile)
Primary-level	971 (8·9%)	10/947	1·1% (0·4 – 1·7)	161/944	17·1% (14·7-19·5)	37/948	3·9% (2·7-5·1)	3 (2-5)
Secondary-level	3433 (31·4%)	61/3337	1·8% (1·4-2·3)	518/3298	15·7% (14·5-16·9)	93/3328	2·8% (2·2-3·4)	3 (2-5)
Tertiary-level	6535 (59·7%)	161/6469	2·5% (2·1-2·9)	1192/6203	19·2% (18·2-20·2)	315/6269	5·0% (4·5-5·6)	3 (2-6)
All	10939	232/10753	2·2% (1·9-2·4)	1871/10445	17·9% (17·1-18·6)	445/10545	4·2% (3·8-4·6)	3 (2-6)

Denominators vary with the completeness of the data. CI confidence interval; IQR interquartile range

Table

Supplementary Table 11. Multivariable model of in-hospital mortality using a per-protocol analysis of DCP3 hospital category compliant data.

	Odds ratio (OR)	95% confidence interval (CI)	P-value
Intercept	0·002	0·000-0·049	0·0001
Patient factors			
Age spline 1	0·988	0·864-1·130	0·86
Age spline 2	1·111	0·125-9·900	0·93
Age spline 3	1·062	0·005-228·722	0·98
Age spline 4	0·702	0·014-34·248	0·86
ASA 1	Reference		
ASA 2	1·529	0·955-2·447	0·08
ASA 3	3·690	2·277-5·981	<0·0001
ASA 4 or 5	10·121	5·872-17·446	<0·0001
Surgical factors			
Elective surgery	Reference		
Urgent surgery	3·512	2·278-5·416	<0·0001
Emergent surgery	4·638	2·992-7·191	<0·0001
Minor surgery	Reference		
Intermediate surgery	1·620	0·987-2·660	0·06
Major surgery	2·444	1·441-4·146	0·0009
Cardiothoracic and vascular surgery	1·833	1·011-3·324	0·05
Ear nose and throat	2·381	1·103-5·137	0·03
Gastrointestinal and hepatobiliary	2·686	1·609-4·482	0·0002
Gynaecology and obstetrics	0·337	0·172-0·660	0·0015
Neurosurgery	3·028	1·481-6·191	0·0024
Other	1·158	0·517-2·593	0·72
Plastics and breast	1·377	0·649-2·921	0·41
Urology	1·771	0·839-3·738	0·13

Countries			
A	2·025	1·036-3·960	0·04
B	1·098	0·305-3·962	0·89
C	0·190	0·025-1·433	0·11
D	1·903	0·955-3·791	0·07
E	1·060	0·489-2·295	0·88
F	2·523	1·288-4·942	0·0070
G	N/A		
H	0·682	0·314-1·483	0·33
I	0·831	0·365-1·893	0·66
J	0·623	0·273-1·419	0·26

DCP3 Disease Control Priorities in Developing Countries classification; ASA American Society of Anesthesiologists; A-J anonymised countries; N/A not applicable as no outcome reported

Table

Supplementary Table 12. Multivariable logistic regression with multiple imputation for missing data

	Main analysis odds ratio without imputation for missing data	Minimum odds ratio obtained with multiple imputation for missing data	Maximum odds ratio obtained with multiple imputation for missing data
Intercept	0·002	0·002	0·002
Patient factors			
Age spline 1	0·990	0·990	0·991
Age spline 2	1·125	1·114	1·141
Age spline 3	0·985	0·951	1·008
Age spline 4	0·773	0·763	0·795
ASA 1	Reference	Reference	Reference
ASA 2	1·438	1·422	1·438
ASA 3	3·627	3·584	3·621
ASA 4 or 5	10·153	10·061	10·158
Surgical factors			
Elective surgery	Reference	Reference	Reference
Urgent surgery	3·296	3·289	3·306
Emergent surgery	4·397	4·379	4·403
Minor surgery	Reference	Reference	Reference
Intermediate surgery	1·699	1·696	1·704
Major surgery	2·595	2·591	2·606
Cardiothoracic and vascular surgery	1·773	1·782	1·791
Ear nose and throat	2·279	2·290	2·298
Gastrointestinal and hepatobiliary	2·599	2·607	2·619
Gynaecology and obstetrics	0·329	0·329	0·331
Neurosurgery	2·794	2·803	2·819
Other	1·133	1·134	1·150
Plastics and breast	1·576	1·579	1·588

Urology	1·684	1·673	1·697
Countries			
A	2·006	1·993	2·018
B	1·080	1·080	1·085
C	0·387	0·384	0·387
D	1·892	1·855	1·892
E	1·062	1·063	1·065
F	2·525	2·525	2·530
G	0·407	0·407	0·408
H	0·667	0·666	0·668
I	0·821	0·809	0·822
J	0·614	0·611	0·615

ASA American Society of Anesthesiologists; A-J anonymised countries; N/A not applicable as no outcome reported

Table

Supplementary Table 13. Multivariable model of in-hospital mortality per-protocol analysis of DCP3 hospital category compliant data, with DCP3 hospital categories forced into multivariable analysis.

	Odds ratio (OR)	95% confidence interval (CI)	P-value
Intercept	0·001	0·000-0·026	<0·0001
Patient factors			
Age spline 1	0·984	0·861-1·126	0·82
Age spline 2	1·182	0·132-10·582	0·88
Age spline 3	0·923	0·004-200·849	0·98
Age spline 4	0·768	0·016-37·733	0·89
ASA 1	Reference		
ASA 2	1·521	0·950-2·435	0·08
ASA 3	3·598	2·220-5·832	<0·0001
ASA 4 or 5	10·205	5·913-17·614	<0·0001
Surgical factors			
Elective surgery	Reference		
Urgent surgery	3·568	2·314-5·500	<0·0001
Emergent surgery	4·779	3·078-7·420	<0·0001
Minor surgery	Reference		
Intermediate surgery	1·599	0·973-2·626	0·06
Major surgery	2·373	1·398-4·029	0·0014
Cardiothoracic and vascular surgery	1·752	0·964-3·185	0·07
Ear nose and throat	2·192	1·013-4·746	0·05
Gastrointestinal and hepatobiliary	2·693	1·612-4·500	0·0002
Gynaecology and obstetrics	0·346	0·176-0·681	0·0021
Neurosurgery	2·682	1·302-5·525	0·0074
Other	1·118	0·498-2·508	0·79
Plastics and breast	1·443	0·679-3·067	0·34
Urology	1·696	0·803-3·585	0·17

Countries			
A	2·194	1·122-4·288	0·022
B	1·055	0·290-3·833	0·93
C	0·185	0·024-1·400	0·10
D	2·237	1·111-4·507	0·024
E	1·091	0·503-2·366	0·83
F	2·660	1·348-5·251	0·0048
G	N/A		
H	0·619	0·284-1·352	0·23
I	0·897	0·393-2·044	0·80
J	0·573	0·251-1·312	0·19
Increasing hospital facility level	1·364	1·039-1·789	0·0252

DCP3 Disease Control Priorities in Developing Countries classification; ASA American Society of Anesthesiologists; A-J anonymised countries; N/A not applicable as no outcome reported

Table

Supplementary Table 14. Multivariable model of in-hospital mortality per-protocol analysis and DCP3 hospital category compliant, with university affiliation forced into multivariable analysis.

	Odds ratio (OR)	95% confidence interval (CI)	P-value
Intercept	0·004	0·000-0·101	0·0008
Patient factors			
Age spline 1	0·973	0·850-1·113	0·69
Age spline 2	1·495	0·164-13·597	0·72
Age spline 3	0·487	0·002-110·182	0·80
Age spline 4	1·298	0·026-65·569	0·90
ASA 1	Reference		
ASA 2	1·496	0·931-2·402	0·10
ASA 3	3·585	2·201-5·838	<0·0001
ASA 4 or 5	9·702	5·594-16·825	<0·0001
Surgical factors			
Elective surgery	Reference		
Urgent surgery	3·545	2·292-5·481	<0·0001
Emergent surgery	4·594	2·942-7·173	<0·0001
Minor surgery	Reference		
Intermediate surgery	1·613	0·981-2·650	0·06
Major surgery	2·440	1·435-4·150	0·0010
Cardiothoracic and vascular surgery	1·919	1·050-3·506	0·03
Ear nose and throat	2·430	1·118-5·280	0·03
Gastrointestinal and hepatobiliary	2·756	1·638-4·639	0·0001
Gynaecology and obstetrics	0·314	0·157-0·630	0·0011
Neurosurgery	3·159	1·533-6·508	0·0018
Other	1·188	0·529-2·669	0·68
Plastics and breast	1·459	0·684-3·112	0·33
Urology	1·872	0·883-3·967	0·10

Countries			
A	2·257	1·117-4·562	0·0234
B	1·132	0·312-4·113	0·85
C	0·184	0·024-1·392	0·10
D	2·037	1·006-4·123	0·0481
E	1·303	0·546-3·111	0·55
F	2·520	1·286-4·941	0·0071
G	N/A		
H	0·434	0·150-1·255	0·12
I	0·865	0·379-1·975	0·73
J	0·693	0·299-1·608	0·39
University-affiliation	0·791	0·499-1·255	0·32

DCP3 Disease Control Priorities in Developing Countries; ASA American Society of Anesthesiologists; A-J anonymised countries; N/A not applicable as no outcome reported

Figure

Figure 1. Participating countries in the African Surgical Outcomes Study

Figure 2. African Surgical Outcomes Study (ASOS) country, hospital and patient recruitment

Footnote: Representative hospitals provided data on the number of eligible patients for the study, and recruited >90% of the eligible patients into the study

Figure 3. Surgical mortality following elective surgery in high-income, low-middle income, and African countries

Footnote: ISOS International Surgical Outcomes Study, ASOS African Surgical Outcomes Study, HIC high income countries, LMIC low-middle income countries

Supplementary Figure 1. Per-protocol calibration plot for the in-hospital mortality multivariable model

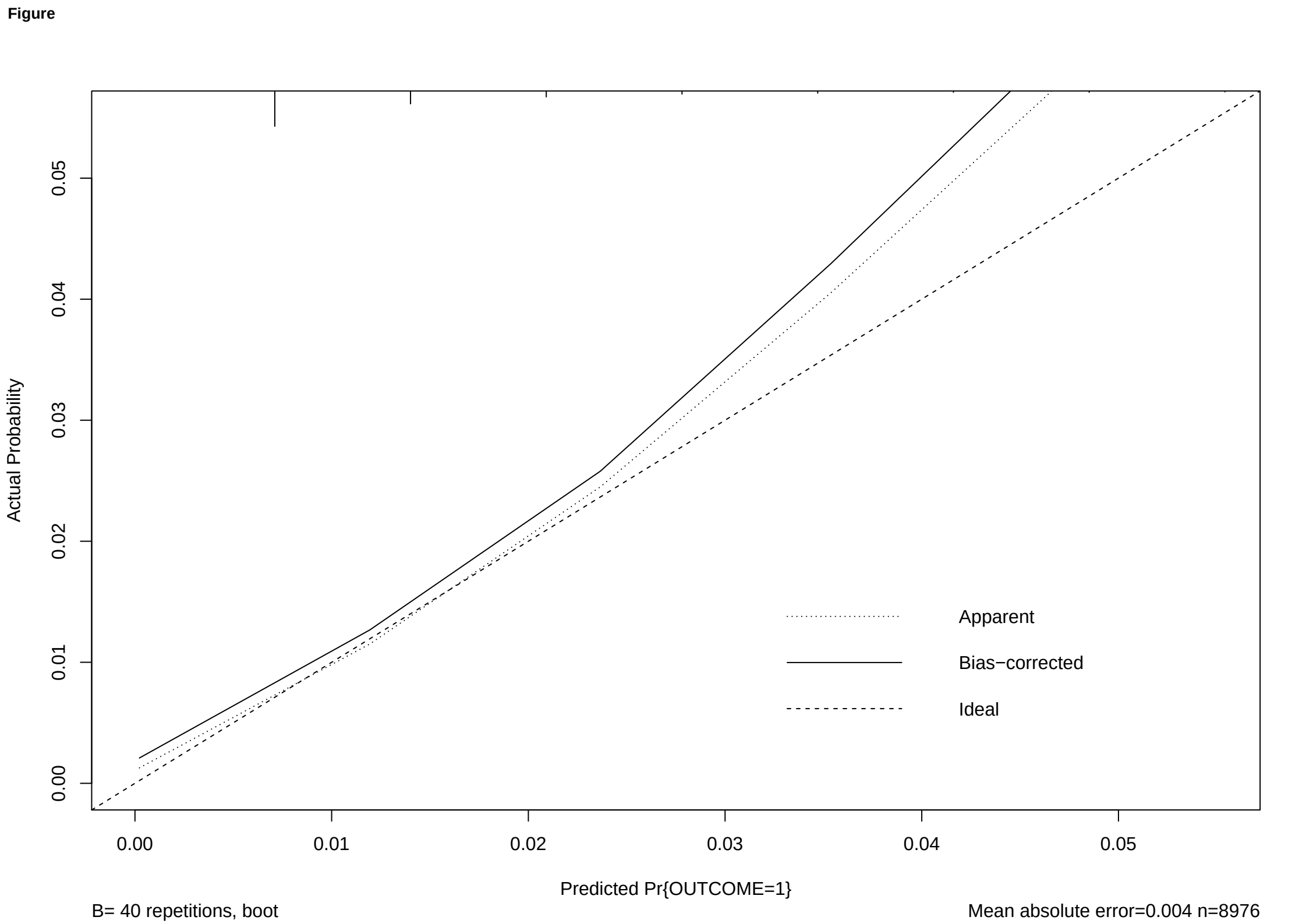
Supplementary Figure 2. Per-protocol sample analysis of surgical mortality following elective surgery in high-income, low-middle income, and African countries

Footnote: ISOS International Surgical Outcomes Study, ASOS African Surgical Outcomes Study, HIC high income countries, LMIC low-middle income countries

Supplementary Figure 3. African regional participation of countries in the African Surgical Outcomes Study

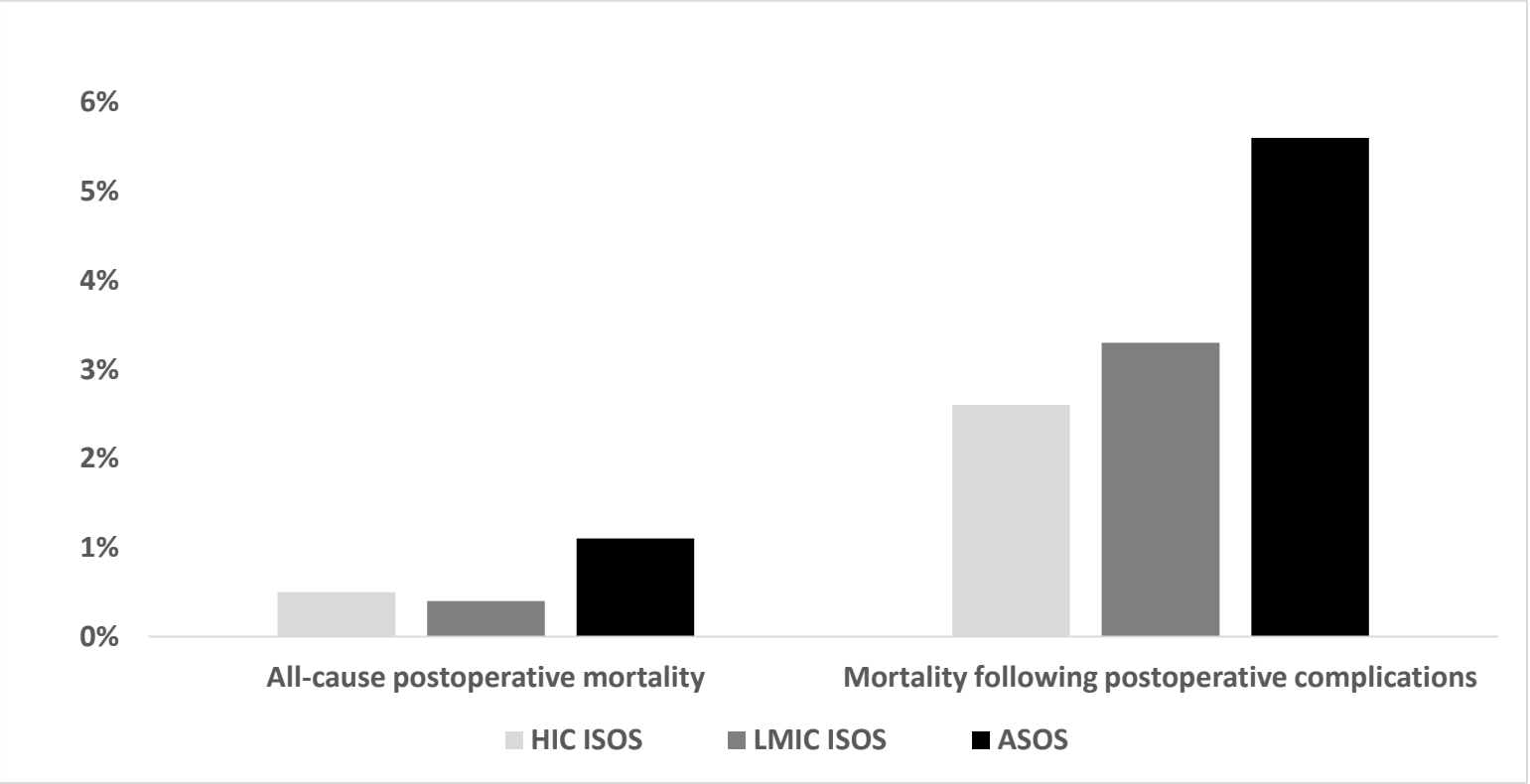
Footnote: Regions include central, eastern, northern, southern, western Africa, and Indian Ocean Islands

Figure


Actual Probability
0.00
0.01
0.02
0.03
0.04
0.05
Predicted Pr{OUTCOME=1}
Apparent
Bias−corrected
Ideal
B= 40 repetitions, boot
Mean absolute error=0.004 n=8976

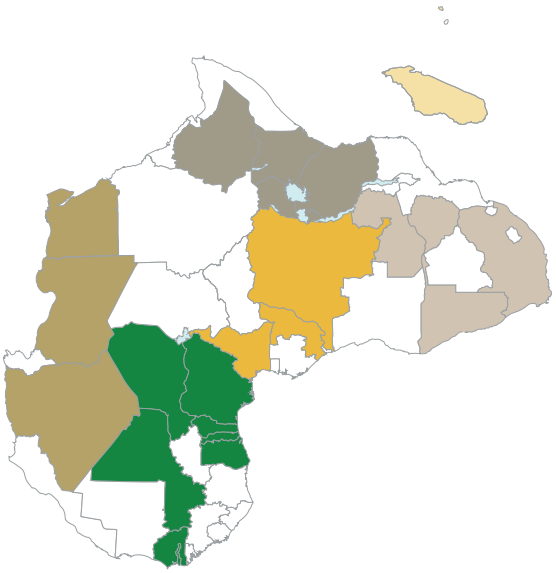
Figure

Supplementary Figure 2. Per-protocol representative sample analysis of surgical mortality following elective surgery in high-income, low-middle income, and African countries



ISOS International Surgical Outcomes Study, ASOS African Surgical Outcomes Study, HIC high income countries, LMIC low-middle income countries

Figure



Supplementary Material

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