

# Effects of hospital facilities on patient outcomes after cancer surgery: an international, prospective, observational study



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## Summary

**Background** Early death after cancer surgery is higher in low-income and middle-income countries (LMICs) compared with in high-income countries, yet the impact of facility characteristics on early postoperative outcomes is unknown. The aim of this study was to examine the association between hospital infrastructure, resource availability, and processes on early outcomes after cancer surgery worldwide.

**Methods** A multimethods analysis was performed as part of the GlobalSurg 3 study—a multicentre, international, prospective cohort study of patients who had surgery for breast, colorectal, or gastric cancer. The primary outcomes were 30-day mortality and 30-day major complication rates. Potentially beneficial hospital facilities were identified by variable selection to select those associated with 30-day mortality. Adjusted outcomes were determined using generalised estimating equations to account for patient characteristics and country-income group, with population stratification by hospital.

**Findings** Between April 1, 2018, and April 23, 2019, facility-level data were collected for 9685 patients across 238 hospitals in 66 countries (91 hospitals in 20 high-income countries; 57 hospitals in 19 upper-middle-income countries; and 90 hospitals in 27 low-income to lower-middle-income countries). The availability of five hospital facilities was inversely associated with mortality: ultrasound, CT scanner, critical care unit, opioid analgesia, and oncologist. After adjustment for case-mix and country income group, hospitals with three or fewer of these facilities (62 hospitals, 1294 patients) had higher mortality compared with those with four or five (adjusted odds ratio [OR] 3·85 [95% CI 2·58–5·75];  $p < 0\cdot0001$ ), with excess mortality predominantly explained by a limited capacity to rescue following the development of major complications (63·0% vs 82·7%; OR 0·35 [0·23–0·53];  $p < 0\cdot0001$ ). Across LMICs, improvements in hospital facilities would prevent one to three deaths for every 100 patients undergoing surgery for cancer.

**Interpretation** Hospitals with higher levels of infrastructure and resources have better outcomes after cancer surgery, independent of country income. Without urgent strengthening of hospital infrastructure and resources, the reductions in cancer-associated mortality associated with improved access will not be realised.

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## Introduction

Of the 15·2 million individuals diagnosed with cancer in 2015, 80% required surgery.<sup>1</sup> For many common, high-burden cancers, including breast, colorectal, and gastric cancers, surgery often offers the best chance of cure, particularly in early-stage disease. 45 million surgical procedures are estimated to be needed worldwide each year to treat cancer, yet fewer than 25% of patients with cancer have access to safe, affordable, and timely surgery.<sup>2</sup>

To address the growing cancer burden in low-income and middle-income countries (LMICs), investments will need to be made in the entire cancer care continuum. This includes surgical treatment for cancer and the services that support high-quality surgical care, such as diagnostic imaging, pathology, perioperative care, and the training of personnel. Investing in cancer care can yield substantial health and economic benefits if investments are closely aligned with country needs.<sup>3</sup> Although a compelling rationale for investing in the

global scale-up of cancer care exists, these data are predominantly based on simulation and extrapolation.<sup>1,3,4</sup>

Little is known about the type or quality of surgical care that patients with cancer receive for common, high-burden cancers around the world, nor the impact of surgical care on survival outcomes. These knowledge gaps make it difficult for countries to identify areas of need and make informed investments in their cancer systems in order to maximise health gains.

We previously showed<sup>5</sup> that patients in LMICs have higher mortality after cancer surgery compared with those in high-income countries, but the impact of hospital facilities on patient outcomes was not explored. Structural characteristics such as case volume, facility availability, and the presence of specialised services are known to affect surgical outcomes in high-income settings.<sup>6–8</sup> Improving hospital facilities through additional infrastructure and resources, translating to greater capacity, is thought to affect clinical outcomes in lower-income settings.

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See [Comment](#) page e936

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See [Online](#) for appendix

**Research in context****Evidence before this study**

Excess mortality after cancer surgery in low-income and middle-income countries (LMICs) has been described previously, but the effects of hospital facilities on early patient outcomes are unknown. Identifying the type and extent of these effects after cancer surgery worldwide is important to broaden understanding, guide further research, and inform national surgical plans. We reviewed the evidence for hospital infrastructure and resource availability on early outcomes following cancer surgery. We searched PubMed, MEDLINE, Google Scholar, and ClinicalTrials.gov for articles published between Jan 1, 1990, and May 10, 2021, using the terms “cancer” OR “malignancy” AND “surgery” AND “hospital” OR “characteristics” OR “facilities” AND “outcomes”, without language restrictions. The studies identified by our search largely focused on single tumour types and compared outcomes within single high-income countries. No studies explored the impact of hospital characteristics on outcomes after cancer surgery across different income settings.

**Added value of this study**

This study provides comprehensive data across income settings on the effect of hospital facilities on early outcomes in patients

undergoing surgery for three common cancers. Even after case-mix adjustment, patients treated in hospitals with lower levels of hospital infrastructure and resources had higher postoperative mortality, despite similar complication rates. Excess mortality after surgery in these hospitals could be explained by the absence of these hospital facilities, which aid early identification and treatment of postoperative complications. The presence of five key hospital facilities is associated with a hospital’s ability to perform safe elective operations for a broad range of cancers, highlighting their importance for access to high-quality, effective global surgical cancer care.

**Implications of all the available evidence**

We estimate that one to three early surgical deaths per 100 patients undergoing cancer surgery in LMICs can be prevented with improvements to hospital infrastructure and resources. These estimates could help policy makers to develop national cancer plans that include scaling up hospital cancer care facilities, together with the current focus on improving access to cancer services.

Estimates suggest that poor-quality health systems cause 8 million deaths per year in LMICs.<sup>9</sup>

Using a systems-based approach, we aimed to describe critical surgical oncology services available worldwide and to investigate whether hospital facilities are associated with improved outcomes after cancer surgery worldwide, particularly in low-income settings, and the potential effects of improving these resources.

**Methods****Study design and participants**

A collaborative, international, multicentre, prospective, observational cohort study was conducted according to a prespecified, published protocol.<sup>10</sup> The collaborative network methodology has been described elsewhere.<sup>11</sup> Briefly, any hospital worldwide providing surgical services for breast, colorectal, or gastric cancer was eligible to take part, with centres collecting observational data on consecutive patients undergoing primary emergency or elective surgery for breast, gastric, or colorectal cancer between April 1, 2018, and Jan 31, 2019. Case ascertainment and data accuracy were high.<sup>5</sup>

The survey design followed a system-based approach, adapting the framework for comprehensive cancer centres in LMICs.<sup>12</sup> Hospital infrastructure and process resources identified as core clinical service components to ensure access to high quality cancer care were captured, such as the presence of imaging modalities, oncology services, surgical treatment, and perioperative care (appendix pp 1–5). The ability of hospitals to perform

elective operations for 11 globally prevalent cancers was also ascertained.<sup>3</sup> 20 surgical experts across nine LMICs reviewed multiple survey iterations, with specific criteria to ensure included hospital facilities had relevance in low-income settings.

Definitions for each hospital facility were taken from WHO,<sup>13</sup> if available, or the National Health Service data dictionary<sup>14</sup> or American Association of Clinical Oncology<sup>15</sup> (appendix pp 1–5). Members listed within the tumour board structure were taken from National Institute for Health and Care Excellence guidelines.<sup>16</sup>

Beta testing at two LMIC hospital sites was performed to ensure survey clarity before formal release across all collaborating hospitals. Collaborators at hospitals who had entered patient-level data for GlobalSurg 3 were invited to complete the hospital-level survey via a secure online link and entered directly onto the REDCap database. Collaborators were provided with a data extraction sheet to aid completion. The survey remained open for 8 weeks, until April 23, 2019, with reminders sent every 4 weeks if the survey remained incomplete. Hospitals were divided into clusters according to income group, with differential sampling across upper-middle and low to lower-middle clusters, where wide variation in hospital characteristics has been described.<sup>9</sup> Independently collected patient-level observational data were then linked to hospital infrastructure and process data in this multimethod analysis.

A UK National Health Service Research Ethics proportionate review considered this study exempt from

formal research registration (South East Scotland Research Ethics Service, reference NR/161AB6) because it was deemed a clinical audit. Individual centres obtained their own audit or institutional approval, together with ethical approval as per local regulations. This study is reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.<sup>17</sup>

### Outcomes

The primary outcome measures were 30-day mortality and 30-day major complication, as defined by Clavien-Dindo grade III, IV, or V.<sup>18</sup> Death was included in the definition of major complication and therefore was not a competing risk. Capacity to rescue was defined as the absolute risk difference of death in patients sustaining a major complication of surgery. Secondary outcome measures, as previously defined in the protocol,<sup>10</sup> were selected as potential surrogate measures for patient safety and cancer care quality within hospitals. These included use of surgical safety checklists, negative resection margin rates, length of in-patient stay, readmission rates, use of a multidisciplinary tumour board meeting to discuss patient management, and follow-up method.<sup>19,20</sup> Patients were assessed at 30 days to determine postoperative outcomes, with follow-up done in person, by telephone, or by review of medical or readmission records, depending on local practices. Due to the differences in morbidity and mortality seen in the surgical management of breast cancer, a subanalysis including only patients with colorectal and gastric cancer was also performed.

### Statistical analysis

11 hospital facilities were selected a priori on the basis of their potential to directly or indirectly affect patient outcomes after cancer surgery.<sup>3,6,7,12,21,22</sup> These facilities were categorised into four areas potentially representing structure and process measures within the hospital that support the management of surgical patients at high risk:<sup>6,12</sup> imaging modalities (ultrasound and CT scan); oncological service organisation (oncologist, pathologist, and tumour board); perioperative care organisation (postoperative recovery area, opioid analgesia, palliative care, and critical care unit [high dependency unit, intensive care unit, or both]); and specialist cancer services (specialist hospital and ability to perform elective oesophagectomy). The relations between elective oesophagectomy, facility availability, service complexity, and mortality are well described in high-income settings.<sup>6,7,21</sup>

Variable selection was performed to select hospital facilities associated with 30-day mortality using the Akaike information criterion, as described by Moons and colleagues.<sup>23</sup> All hospital facilities were included as explanatory variables within this model, with the exclusion of patient-level data. Only main interactions were included

to avoid overfitting. As a sensitivity analysis, a bootstrap procedure (n=5000) was performed to investigate variability in hospital facility selection. To obtain adjusted outcomes at hospitals with different numbers of facilities, we created an ordinal variable from selected variables, which represented the number of facilities at each hospital. Hospitals were then categorised into tertiles by patient distribution to define different facility levels.

Variation across different international health settings was assessed by stratifying countries by World Bank country group classifications. Differences between groups were tested with the Pearson  $\chi^2$  test for categorical variables and with the Kruskal-Wallis test for continuous variables. To characterise the relation between hospital facilities and mortality, generalised estimating equations were constructed to account for income group, case mix (patient and disease factors), and operative characteristics known to be associated with worse outcomes after cancer surgery,<sup>5</sup> with population stratification by hospital.

Adjusted outcomes were calculated as predicted probabilities from a generalised estimating equation logistic regression model, including potential confounders (patient age, sex, American Society of Anesthesiologists grade, Eastern Cooperative Oncology Group performance status, disease stage, and operative urgency) across income group and cancer type. We obtained 95% CIs and a p value for trend by fitting the generalised estimating equation logistic regression model with facility capability.

Sensitivity analyses for adjusted outcome rates were performed by imputing the average number of available hospital facilities by nearest neighbour human development index rank for missing hospitals. As an additional comparison, adjusted outcomes were also calculated using all 11 hospital facilities (ordinal value 0–11) across included hospitals using the same method.

The association between hospital facility level and 30-day mortality was calculated from logistic regression models for different covariate levels (patient and disease characteristics). Absolute risk differences and 95% CIs were calculated using bootstrap resampling (5000 draws). The number needed to treat to benefit was defined as the reciprocal of the absolute risk difference.

All p values were two-sided and were considered statistically significant if the p value was less than 0.05. All analyses were done using R (version 4.1.1), using finalfit, tidyverse, geepack, epitools, and bootStepAIC.

This study was prospectively registered with ClinicalTrials.gov, NCT03471494.

### Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

### Results

Between April 1, 2018, and April 23, 2019, hospital-level data were collected with differential sampling across

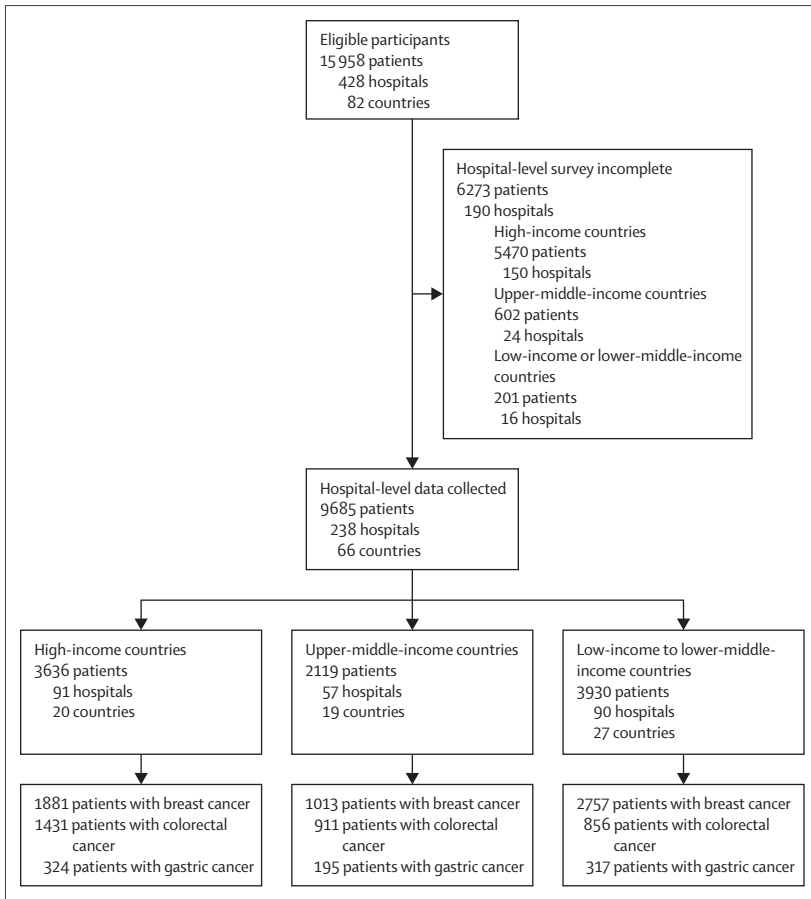


Figure 1: Study flowchart

LMICs for 238 hospitals in 66 countries that surgically treated 9685 patients with cancer (91 hospitals in 20 high-income countries [3636 patients]; 57 hospitals in 19 upper-middle-income countries [2119 patients]; and 90 hospitals in 27 low-income or lower-middle-income countries [3930 patients]; figure 1). Incomplete surveys were due to non-responses across all income groups, rather than incomplete data submission. The characteristics of included hospitals by income group are summarised in table 1. Hospital facilities varied by income group except for the presence of ultrasound, pathology services, and performance of elective oesophagectomy.

Elective procedures were similar across all income groups, with the exceptions of liver, pancreas, and rectal surgery (appendix p 6). The distribution of elective procedures stratified by the ability of a hospital to surgically treat breast, colorectal, and gastric cancer is shown in the appendix (p 6). A stepwise increase in all hospital facilities was seen as the total number of available facilities within a hospital increased (appendix p 7). Across colorectal and gastric cancer, unadjusted mortality rates reduced as overall hospital facility count increased (appendix p 8). For hospitals where hospital-level data were not available, case volume and adjusted mortality rates were found to be similar to rates in hospitals with hospital-level data available stratified by income group and cancer type (appendix pp 9–10).

Five hospital facilities were inversely associated with 30-day mortality and covered a broad range of resources (ultrasound, CT scanner, oncologist, opioid analgesia, and critical care unit; appendix p 11). The same five facilities were identified in a sensitivity analysis using bootstrap resampling (appendix p 12). Of the 238 hospitals included, 113 (47%) had all five of these hospital facilities present (figure 2). The number of available hospital facilities declined with worsening human development index rank, particularly in countries with a rank of more than 150 (figure 2C).

After categorisation by patient distribution, three hospital facility levels were identified (113 hospitals with five facilities available; 63 hospitals with four facilities; and 62 hospitals with three or fewer facilities). Patient distribution across the three hospital facility levels is shown in the appendix (pp 13–14). Patients at hospitals with three or fewer facilities were more likely to be from low-income settings and to present with colorectal or gastric cancer. These patients had poorer performance status, more advanced disease, and were more likely to require emergency surgery, with higher rates of postoperative surgical site infection (appendix p 15).

Hospitals with three or fewer facilities were less likely to use the surgical safety checklist (73.6% vs 83.7% for hospitals with more than three facilities;  $p < 0.0001$ ), to have a negative resection margin (87.5% vs 90.8%;  $p = 0.0005$ ), to review patients in clinic after discharge (45.6% vs 75.9%;  $p < 0.0001$ ), and to discuss patient

	High (n=91)	Upper middle (n=57)	Low or lower middle (n=90)	Total (n=238)	p value
Tumour board availability	89 (98%)	53 (93%)	71 (79%)	213 (89%)	0.0001
Oncologist available in hospital	85 (93%)	46 (81%)	63 (70%)	194 (82%)	0.0002
Palliative care available in hospital	68 (75%)	28 (49%)	37 (41%)	133 (56%)	<0.0001
Opioid medication available	84 (92%)	48 (84%)	47 (52%)	179 (75%)	<0.0001
Ultrasound available	77 (85%)	52 (91%)	75 (83%)	204 (86%)	0.38
CT scan available	87 (96%)	48 (84%)	54 (60%)	189 (79%)	<0.0001
Postoperative care facilities	86 (95%)	45 (79%)	62 (69%)	193 (81%)	<0.0001
Critical care bed available	84 (92%)	44 (77%)	60 (67%)	188 (79%)	0.0001
Pathology available in hospital	66 (73%)	46 (81%)	62 (69%)	174 (73%)	0.29
Hospital type					
Non-referral hospital	25 (27%)	3 (5%)	5 (6%)	33 (14%)	0.0001
Referral hospital	56 (62%)	46 (81%)	73 (81%)	175 (74%)	..
Specialist cancer hospital	10 (11%)	8 (14%)	12 (13%)	30 (13%)	..
Elective oesophagectomy available	44 (48%)	34 (60%)	46 (51%)	124 (52%)	0.40

Data are n (%), unless indicated otherwise.

**Table 1: Distribution of hospital facilities by country income group**

management through a multidisciplinary tumour board (31.3% vs 78.3%;  $p < 0.0001$ ), and they had longer in-patient stays (5 days [IQR 3–9] vs 3 days [1–7];  $p < 0.0001$ ; appendix pp 16–17). The availability of surgical treatment for several common cancer types was also reduced in hospitals with three or fewer facilities (appendix p 18).

After adjusting for patient and disease factors, 30-day mortality rates were higher in hospitals with three or fewer facilities across all cancers (3.7% vs 1.0% in hospitals with five facilities; OR 3.85 [95% CI 2.58–5.75];  $p < 0.0001$ ; appendix p 19). No difference in adjusted mortality rates was seen in hospitals with four facilities available compared with those with five. A sub-analysis showed a similar finding in patients with colorectal and gastric cancer (6.9% vs 4.1%; 1.73 [1.18–2.52];  $p = 0.0063$ ; appendix p 20).

Adjusted 30-day major complication rates were higher in hospitals with three or fewer facilities across all three cancers (11.8% vs 9.3% in hospitals with five facilities; OR 1.30 [95% CI 1.06–1.58];  $p = 0.011$ ) and for patients with colorectal and gastric cancer (18.0% vs 13.5%; 1.40 [1.11–1.78];  $p = 0.0076$ ; appendix p 21). After the development of a major complication, the capacity to rescue patients was significantly lower in hospitals with three or fewer facilities across all cancers (63.0% vs 82.7% in hospitals with five facilities; OR 0.35 [0.23–0.53];  $p < 0.0001$ ; table 2) and for patients with colorectal and gastric cancer only (56.4% vs 71.5%; 0.51 [0.33–0.80];  $p = 0.0044$ ). All effects persisted in a sensitivity analysis using an imputed dataset (appendix pp 23–26).

The absolute risk differences for 30-day mortality across hospital facility level were examined for common patient covariates in patients with colorectal and gastric cancer (figure 3; appendix p 26). The presence of four or more hospital facilities was associated with fewer deaths in the low-income to lower-middle-income group (two to three fewer deaths per 100 operations, number needed to treat 33–50), the upper-middle-income group (one to two fewer deaths per 100 operations, number needed to treat 50–100), and the high-income group (one fewer death per 100 operations, number needed to treat 100). Absolute differences across the three hospital facility levels are shown in the appendix (pp 27–29).

In a post-hoc analysis, we determined the absolute risk for 30-day mortality for higher-risk surgical patients, using common patient covariates for patients with an American Society of Anesthesiologists grade of 3 or higher (appendix pp 30–31). An increase in absolute risk difference was found across different levels of hospital facility in the low-income to lower-middle-income group (four to five fewer deaths per 100 operations, number needed to treat 20–25), the upper-middle-income group (two to three fewer deaths per 100 operations, number needed to treat 33–50), and the high-income group (one fewer death per 100 operations, number needed to treat 100).

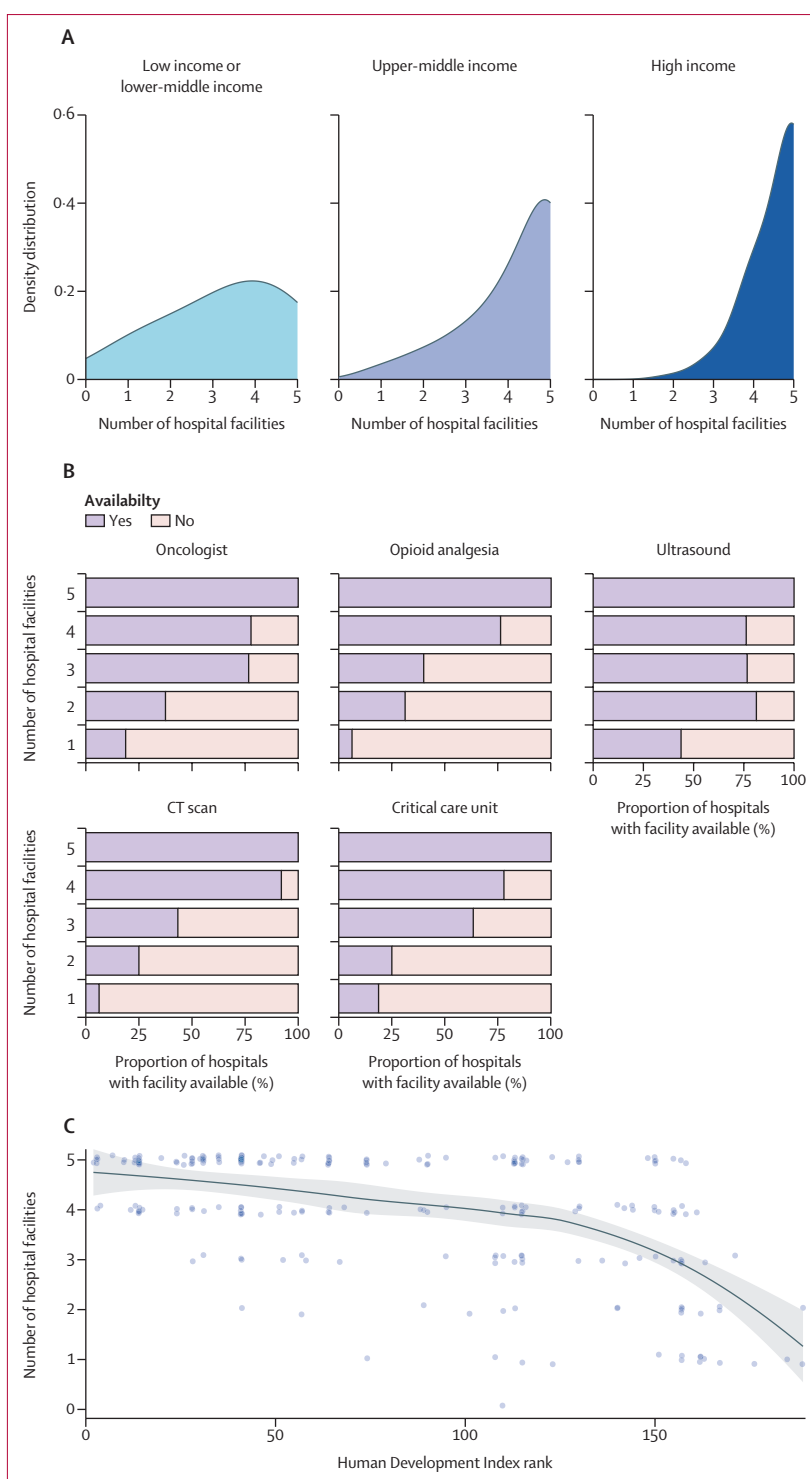


Figure 2: Distribution of hospital facilities by World Bank income group (A), individual hospital facility (B), and human development index rank (C)

## Discussion

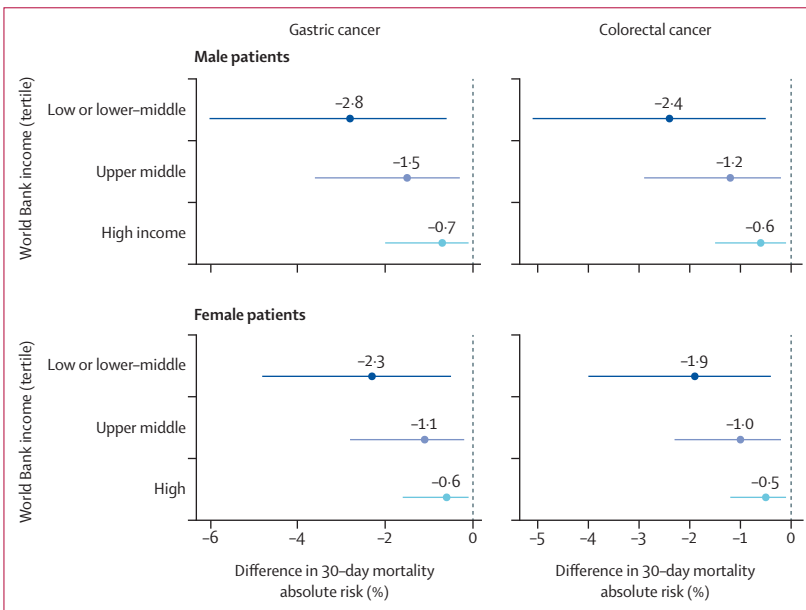
In this prospective study of patients undergoing cancer surgery in 238 hospitals from 66 countries, higher



	Hospitals, n (%)	Patients, n (%)	Adjusted capacity to rescue, % (95% CI)	Odds ratio (95% CI)	p value
<b>All cancers (n=170)</b>					
Five facilities	86 (51%)	569 (65%)	82.7% (81.1-84.4)	1 (ref)	..
Four facilities	43 (25%)	173 (20%)	77.9% (74.6-81.3)	0.74 (0.49-1.13)	0.18
Three or fewer facilities	41 (24%)	134 (15%)	63.0% (58.4-67.6)	0.35 (0.23-0.53)	<0.0001
<b>Colorectal and gastric cancer (n=148)</b>					
Five facilities	73 (49%)	320 (58%)	71.5% (69.3-73.7)	1 (ref)	..
Four facilities	41 (28%)	119 (22%)	69.5% (65.5-73.5)	0.92 (0.58-1.45)	0.72
Three or fewer facilities	34 (23%)	110 (20%)	56.4% (51.8-60.9)	0.51 (0.33-0.80)	0.0044

Adjusted rates of capacity to rescue after major complication were calculated using generalised estimating equations to account for clustering of patients in hospital and for potential confounders (World Bank tertile, age, sex, cancer type, Eastern Cooperative Oncology Group performance status, American Society of Anesthesiologists grade, disease stage, and surgical urgency). 95% CIs and p values for trend were fitted using the multilevel logistic regression model with the number of available hospital facilities and all confounders as covariates.

**Table 2: Capacity to rescue patients after a major complication after case-mix adjustment, by number of hospital facilities**



**Figure 3: Absolute risk of 30-day mortality associated with four or more hospital facilities within each income group, stratified by cancer type and sex**  
 Estimates are shown for a patient of age 60 years, Eastern Cooperative Oncology Group performance status 1, American Society of Anesthesiologists grade 2, cancer stage III, and elective surgery. The grey dashed line represents three or fewer hospital facilities available and bars represent absolute risk of 30-day mortality with 95% CIs.

availability of specific hospital infrastructure and resources was associated with improved outcomes. Hospitals that were well resourced had less than half the postoperative mortality rate, showing an improved ability to prevent death after the development of postoperative complications, with up to three fewer deaths per 100 operations performed. Of note, these findings were independent of country income group. The availability of hospital resources has long been thought to affect clinical

outcomes in lower-income settings; the magnitude of this effect is now clear.

Despite the overall mortality benefit seen in hospitals with more resources and strong processes, many patients do not have access to such hospital infrastructure, particularly in low-income settings.<sup>24</sup> Improvements to hospital facilities are known to be cost-effective,<sup>3</sup> but the absence of high-quality data limits interpretability, and the effects of specific hospital facilities on outcomes and cancer surgery worldwide were previously unclear. Strategic planning requires detailed and accurate information to allocate appropriate resources, prioritise quality improvement, and evaluate effects. Determining the effectiveness of hospital infrastructure can guide future investment and provide a platform for continued assessment of hospital performance.

Our results offer a concrete approach by focusing on specific infrastructure and resources in hospitals worldwide. Such hospitals perform significantly better than others without them; in the 62 hospitals with three or fewer facilities, mortality rates were three times higher than in the 113 hospitals with all five facilities present. This difference is likely to be explained by a 50% increase in the capacity to rescue patients after the development of a major complication. These findings were robust in a sensitivity analysis and a similar trend was identified when all 11 hospital facilities were included. These results show that a strategy of expanding system capabilities at hospitals, particularly in low-income and middle-income settings, could markedly improve outcomes and patient access to safe, effective surgical care.

Previous studies have reported similar associations between key hospital facilities and mortality. Funk and colleagues<sup>6</sup> found that the presence of complex medical oncology services and specific radiology services were important for lowering mortality in patients undergoing oesophagectomy. Similarly, Joseph and colleagues<sup>25</sup> found that several institutional characteristics had a stronger effect on operative mortality after pancreatic resection than hospital volume. However, differences in major morbidity after surgery are often undescribed.<sup>6,21</sup>

To our knowledge, this is the first global analysis to assess the impact of hospital facilities on short-term outcomes in cancer surgery. The synergistic effect of scaling up of imaging, treatment modalities, and quality in low-income settings on oncological outcomes has been shown in studies from 2021.<sup>3,4</sup> In particular, investments in imaging modality availability are a critical component for comprehensive improvement in global cancer survival.<sup>3</sup>

However, our results must be interpreted with caution. We suspect that these facilities are proxies for the expertise, resources, and complex processes of care required to facilitate surgery, including the optimisation of preoperative, intraoperative, and postoperative care for patients undergoing surgery for cancer. The presence of a CT scanner is unlikely to directly improve patient

outcomes without associated investment in additional supportive capacity, such as health-care workers and technical support. The five key facilities that were included in our multivariable models are likely to be indirect markers for other structural and process measures that are also closely related to outcomes after cancer surgery. For example, we found that hospitals with more resources were more likely to use the WHO surgical safety checklist and have negative resection margins, potentially reflecting related organisational processes associated with these facilities. A similar pattern in outcomes was shown in models including all 11 of the hospital facilities originally assessed, suggesting that the five facilities identified in our analysis might also reflect further development of additional hospital services.

Higher levels of hospital facility were also associated with increased access to surgical care for a broad range of cancer types. The majority of hospitals with all five facilities present were able to perform elective operations for 11 different cancers, which represent 60% of all incident cancers and 70% of cancer deaths worldwide over the next 10 years.<sup>3</sup> Patients also presented with earlier stage disease, suggesting hospital facility improvement could be associated with concurrent investment in early detection programmes and strengthening of health-care systems. Similar outcomes were found between hospitals with four or five key facilities, which could suggest a ceiling effect between expanding system capabilities and outcome improvement.

Centres providing cancer care worldwide vary in size, scale, and structure. Designated cancer centres, referral networks, and standardised cancer pathways are underdeveloped or absent in many LMICs.<sup>26</sup> The centralisation of services into comprehensive cancer centres, supported by our analysis, is likely to improve quality of care, particularly in resource-constrained environments. However, centralisation can unintentionally reduce access to safe and effective cancer care, secondary to geographical and financial barriers for patients, particularly in the absence of robust referral mechanisms.<sup>12</sup> Therefore, selection of a geographical location to serve the greatest number of patients, while defining the minimum requirements of a comprehensive cancer centre, is crucial.<sup>26</sup> Efforts to improve the quality of cancer care must occur alongside efforts to increase access to care, to maximise health gains and develop equitable cancer systems.

Our study has important limitations. We have detailed hospital-level data for 55% of hospitals within the primary study, with a lower response rate from high-income hospitals. However, we covered 87% of patients in LMIC settings, where the majority of all cancer deaths occur.<sup>27</sup> Furthermore, case volume and adjusted mortality rates of non-included hospitals were similar, and a sensitivity analysis indicated robust findings across all measured outcomes. Therefore, an association between missing

responses and measured outcomes is unlikely. Despite including validated measures of overall patient health, we were unable to account for detailed patient comorbidity across income group within the adjusted models due to the burden of additional data collection, particularly in low-resource settings.

The five hospital facilities identified could represent additional, unmeasured structural and complex care processes. Despite capturing a broad range of hospital infrastructure and resources, we are unable to extrapolate our results to all the additional resources that a hospital might contain. However, as the number of hospital facilities increased, an increase in the capacity to rescue patients was shown. Therefore, investment and improvement in overall hospital capability is likely to greatly improve early patient outcomes after cancer surgery. However, in countries without universal health care, additional investment in hospital facilities must avoid unaffordable increases in total costs to patients for safe surgical care. Further work validating our findings and exploring the effect of specific combinations, particularly in LMIC settings, is required.

Additionally, we were unable to follow up patients beyond 30 days after surgery. Little is known about longer-term outcomes, such as cancer-free survival, in resource-limited settings.<sup>13</sup> Nevertheless, postoperative complications after major surgery can affect longer-term outcomes, including patient survival and disability.<sup>22</sup> Longer-term disease and overall survival after surgery might be lower in LMICs, particularly because patients presented with later stage disease. The impact of delayed surgery in life-years lost for stage I–III disease is well described in high-income countries,<sup>28</sup> but knowledge gaps exist globally. Furthermore, only patients undergoing primary surgery for breast, colorectal, and gastric cancers were included, and therefore our conclusions might not translate across other globally prevalent cancers. The current study will be extended to capture longer-term outcomes and other cancers in the future, which should add substantially to knowledge of the impact of hospital infrastructure and resources on global surgical outcomes.

Finally, we did not have information on surgeon volume or nurse-to-bed ratio, which are both known mediators in the association between hospital facilities and mortality.<sup>25</sup> Debates are ongoing as to whether hospital volume versus hospital process is the primary reason for lower perioperative mortality in cancer surgery,<sup>25,29</sup> particularly because available clinical resources often increase with hospital volume.<sup>25</sup> Additional studies are required to determine their effects on hospital mortality globally.

In conclusion, the number of patients undergoing surgery in hospitals with reduced resources and weak processes of care is higher in low-income and middle-income settings, putting these patients at additional risk. Although early mortality after cancer surgery is known to

be increased in LMICs, the improvement of facilities, processes, and quality of care can dramatically reduce perioperative mortality in these settings. A more comprehensive study of systems strengthening and improvement interventions to reduce postoperative mortality would provide important information on mechanisms to improve cancer surgery outcomes for the large numbers of patients who receive care at these institutions.

#### Writing group

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#### Declaration of interests

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#### Data sharing

The dataset can be explored using an online visualisation application (<https://cancer.globalsurg.org>). Hospital-level data can be shared by application to the corresponding author. For analyses of patient-level identifiable data within our trusted research environment, please contact the corresponding author.

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