30-day postoperative mortality and the effects of hospital preparedness during the COVID-19 pandemic: a pooled analysis of prospective international cohort studies

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Summary

Background Surgical services were poorly prepared for the COVID-19 pandemic, leading to widescale disruption to elective activity. This study aimed to identify actionable priorities to strengthen pandemic preparedness of surgical and hospital systems.

Methods This study pooled data from three international, prospective cohort studies including patients who had a positive SARS-CoV-2 test result in the seven days before or within 30 days after surgery. Patients were included across four pandemic time periods: Period 1 (January–May 2020), Period 2 (June–July 2020), Period 3 (October 2020), and Period 4 (December–March 2022). The primary outcome measure was 30-day postoperative mortality. Hierarchical logistic regression models were developed to explore association between pandemic periods (primary analysis) and hospital-level preparedness (secondary analysis) on 30-day postoperative mortality. Hospital preparedness was classified in to poorly-, moderately-, and highly-prepared tertiles based on Surgical Preparedness Index (SPI) score.

Findings A total of 31,751 patients were included from 1589 hospitals and 102 countries. From Period 1 through to Period 4 there was a decrease in the proportion of patients aged ≥70 years and with ASA grades 3–5.30-day postoperative mortality fell from Period 1 (18.4% [1378/7502]), Period 2 (9.9% [219/2234], adjusted odds ratio (aOR) 0.65, 95% confidence interval (CI) 0.53–0.78), Period 3 (10.5% [246/2427], aOR 0.60, 95% CI 0.50–0.71), through to Period 4 (5.8% [1132/19,588], aOR 0.33, 95% CI 0.30–0.37). During Period 4, SARS-CoV-2 vaccinated patients had lower mortality compared to unvaccinated patients (4.9% [603/12,361] versus 7.4% [529/7178], aOR 0.49, 95% CI 0.42–0.57). Compared to poorly-prepared hospitals (11.2% [1019/9071]), moderately-prepared (9.4% [857/9071], aOR 0.84, 95% CI 0.75–0.94) and highly-prepared hospitals (5.8% [530/9071], aOR 0.70, 95% CI 0.62–0.80) had lower mortality.

Interpretation Postoperative mortality decreased over the course of the COVID-19 pandemic and was lower in better prepared hospitals. Hospitals are critical national infrastructure and strengthening their preparedness by developing formal pandemic plans, establishing patient and procedure prioritisation protocols, and ring-fencing surgical beds would ensure safer surgical care during future pandemics.

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Keywords: Pandemic preparedness; Health system preparedness; COVID-19; SARS-CoV-2; Surgery; Postoperative mortality

Introduction

The 2022 Lancet Commission described how the COVID-19 pandemic led to widescale societal disruption and economic losses, including over 6.9 million deaths worldwide.[1] The high-risk of a new pandemic,[1,2] means that pandemic preparedness is a priority for the World Health Organisation (WHO),[3] the Coalition for Epidemic Preparedness Innovations (CEPI), the G7 and G20 health initiatives, national pandemic task forces,[4,5] and non-governmental organisations, including the Gates Foundation.[6] The WHO's Health Systems Resilience Framework[7] emphasises the importance of

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Research in context

Evidence before this study

Surgical services were poorly prepared for the COVID-19 pandemic, leading to widescale disruption and cancellation of elective activity. Perioperative SARS-CoV-2 infection during the first pandemic wave was associated with significantly increased mortality, but it is unknown how mortality changed over the course of the pandemic and what factors contributed to this. We performed a structured review on MEDLINE for studies published up to December 1, 2024, using the terms "preparedness" OR "resilience" AND "hospital" OR "country" AND "outcomes". We found several international studies (CovidSurg-1 and 2) national cohort studies (England, France, USA) describing outcomes in patients undergoing surgery at specific pandemic periods. We found one study assessing the association of country-level Global Health Security and Joint External Evaluation indices and country-level SARS-CoV-2 infection rates. We did not find any studies reporting changes in perioperative outcomes over the course of the pandemic or the impact of hospital-level preparedness on clinical outcomes. We searched for policy documents related pandemic preparedness, including the Lancet Commission on COVID-19, and found that these focussed exclusively on the regional and national planning with minimal attention to hospital-level preparedness.

Added value of this study

This study aimed to provide longitudinal evidence to identify actionable targets to strengthen hospital pandemic preparedness. It included prospective data on patients with perioperative SARS-CoV-2 infection from 1598 hospitals in 102 countries. It found that 30-day postoperative mortality reduced over the course of the pandemic. Using the Surgical Preparedness Index to measure hospital-level preparedness, we have demonstrated for the first time that better prepared hospital systems have better patient-level outcomes during a pandemic. Key domains that were strongly associated with lower postoperative mortality were developing formal plans, patient- and procedure prioritisation, and ring-fenced beds.

Implications of all the available evidence

During pandemic surges hospitals should implement measures to keep patients safe including patient prioritisation protocols, vaccination, and infection control measures such as transmission-free pathways. When infection rates fall, hospitals should rapidly de-escalate these measures to reopen to minimise disruption to patient pathways and reduce treatment delays. Preparedness is critical to ensuring hospitals are agile in ensuring patient safety during periods of external pressures. The Surgical Preparedness Index should be used to measure hospital-level preparedness and drive continuous improvement and this requires dedicated funding. These findings are generalisable to a broad range of health security risks, including extreme weather events and natural disasters, conflicts, and terrorism.

building adaptive and integrated health systems that can withstand shocks, ensure continuity of essential services, and promote rapid recovery during health emergencies.[8,9]

Health services were severely impacted by the COVID-19 pandemic, because of both the need to divert hospital beds, staff, and resources to support COVID-19 care, and the need to maintain infection prevention measures. This led to disruption across all care pathways,[10] but elective surgery was particularly impacted with millions of operations cancelled worldwide,[11] in part because of the finding that perioperative SARS-CoV-2 infection was associated with significantly increased mortality.[10,12] Whilst urgent research led to evidence-based strategies to reopen surgery,[13–15] globally the recovery of surgical systems has been slow, exacerbating waiting lists[16] and severely setting back progress towards achieving the Lancet Commission on Global Surgery[17,18] targets.

The aim of this study was to produce actionable evidence-based recommendations to strengthen preparedness of surgical and hospital systems and inform future pandemic response and recovery. To achieve this, we have pooled data from the two published CovidSurg cohort studies[10,19] with fresh data from the unpublished CovidSurg-3 cohort study to explore longitudinal trends in surgical care over the course of the COVID-19 pandemic. In addition, we have used the validated Surgical Preparedness Index[20] (SPI) to the influence of hospital-level preparedness on patient outcomes.

Methods

Objectives and primary outcome

The objectives of this study were firstly, to determine whether mortality changed over the course of the COVID-19 pandemic and secondly, to determine the influence of hospital-level preparedness on patient outcomes. The primary outcome measure was the 30-day postoperative mortality, defined as death within 30-days from surgery, with the day of surgery defined as day zero.

Study design and setting

This study includes data from the three international, prospective, observational cohort studies delivered through the CovidSurg Collaborative. These studies had harmonised protocols and consistent patient inclusion criteria. TheCovidSurg-1 and CovidSurg-2 (SurgWeek) cohort studies have previously been published,[10,19] whereas the CovidSurg-3 data has not previously been published. Patient data from these studies were split in to four distinct pandemic periods: Period 1 (January–May 2020, peak of the first pandemic wave), Period 2 (June–July 2020), Period 3 (October 2020, emergence of the Alpha (B.1.1.7) and Delta (B.1.617.2) variants), and Period 4 (December–February 2022, emergence of the Omicron (B.1.1.529) variant). A detailed description of the different pandemic periods is in the Appendix (p11).

Inclusion criteria

Participating hospitals collected data on consecutive eligible patients who had a positive SARS-CoV-2 PCR or rapid antigen test result in the seven days before or 30 days after surgery. Patients were identified based on SARS-CoV-2 tests performed as part of routine clinical care as no additional tests were performed as part of this study. Any surgery performed by a surgeon in an operating theatre for any indication was included, with the exception of minor procedures as previously defined.[19] Patients were only enrolled in any one study once; if they underwent multiple operations within a study window, the procedure closest to the time of their positive SARS-CoV-2 test result was taken as the index procedure.

Data collection and integrity

Patient, disease, and operation factors were collected. Patient factors were age, sex, American Society of Anaesthesiologists (ASA) physical status classification grade, and Revised Cardiac Risk Index (RCRI) score (categorised as 0, 1, 2, ≥3). Disease factors were indication for surgery (trauma, cancer, benign), urgency of surgery (elective, emergency), and timing of SARS-CoV-2 diagnosis (preoperative versus postoperative based on the timing of the first positive test sample). Elective surgery was defined as surgery on a planned admission to hospital, whereas emergency surgery was defined as surgery on an unplanned admission to hospital. Operative data that were collected were grade of surgery (minor, major), and general anaesthesia use. Grade of surgery was recorded based on the BUPA Schedule of procedures.[19,21] In addition, patients were recorded as vaccinated if they had received a first COVID-19 dose, at least two weeks before surgery. Countries were classified as high- (HIC), upper middle (UMIC) or lower middle or low income (LMLIC) based on the 2022 World Bank country income classification.[10] All data captured were uploaded anonymised.

Data were collected through a secure online Research Electronic Data Capture (REDCap) database.[22] Integrity of data quality was maintained through previously described strategies (Appendix p12).[10] Follow-up was based on data captured from written patient notes and computer records relating to inpatient stay and at routine follow-up visits or telephone calls.

Hospital-level assessment

SPI was developed through an international Delphi consensus process in 2021 to assess hospital readiness to sustain elective surgical services during pandemics.[9] It is comprised of 23 domains relating to facilities and consumables (n = 11), staffing (n = 2), prioritisation (n = 2), and hospital systems (n = 8). Hospitals are scored from 23 (least prepared) to 115 points (most prepared) (Appendix p13). SPI has previously been demonstrated to be associated with hospital-level performance measured using the surgical volume rate (ratio of the observed surgical volume against expected surgical volume) as a marker of pandemic-related disruption to elective surgical care.[9] However, it has not previously been validated against surgical outcome measures.

We used SPI to understand the influence of hospital preparedness on patient outcomes during the pandemic, categorising participating hospitals by SPI score as poorly-prepared, moderately-prepared or highly-prepared.[5] Hospital-level assessments of preparedness were evaluated at two timepoints in participating hospitals. The first assessment made between June 6, 2021 and August 5, 2021 was linked to patient-level data from Pandemic Periods 1–3 and the second assessment made between December 13, 2021 and February 28, 2022 was linked to patient-level data from Pandemic Period 4. SPI measurements were assigned to each patient based on the hospital and pandemic period in which they were operated; all patients within the same hospital within a given pandemic period were assigned the same value. Patient data from hospitals for which a SPI rating was not available were excluded from the secondary analyses requiring SPI data. The data used in this study has not previously been used to validate SPI.

Statistical analysis

This study was conducted according to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology)[23] statement. The $\chi 2$ test was used for categorical data. Non-parametric data summarised with medians and interquartile ranges and differences between the groups were tested using the Mann–Whitney U test. Parametric data were summarised with mean and standard deviation. Differences between groups were explored using a two-tailed Student's t-test (two comparator groups) or one-way Analysis of Variance (ANOVA, three or more comparator groups). Further description of the statistical methodology is presented in the Appendix (p14). Statistical significance was defined as a p-value of <0.05. Data analysis was conducted using R (version 3.2.2), with performed using R Foundation Statistical software (R 3.2.2) with TableOne, finalfit, dplyr, ggplot2, Hmisc, and mgcv packages (R Foundation for Statistical Computing, Vienna, Austria).

Primary analysis

The primary analysis of this study was to explore the association between the four pandemic periods on 30-day postoperative mortality. Multilevel logistic regression models were constructed to account for clinically plausible patient, disease, and operation factors that were selected a priori, informed by the findings of previous analyses of the CovidSurg-1 and CovidSurg-2 datasets (Appendix p14). For all these analyses, both hospital and country were included as random effects. Multicollinearity among covariates in the logistic regression models was assessed by calculating variance inflation factors; all variance inflation factors were below the commonly accepted threshold of 5, indicating that collinearity did not bias the model estimates.

Secondary analyses

We performed three secondary analyses to understand the association between hospital preparedness, measured using SPI, and 30-day postoperative mortality. Firstly, hospital-level SPI categories were developed as tertiles $(-\infty, [33]\ ]$, $(x\ [33], x\ [66]\ ]$ and $(x\ [66], +\infty)$ where x [33], and x [66] are, respectively, the 33rd, and 66th percentiles of SPI. To explore the relationship between hospital-level SPI and 30-day mortality, multilevel logistic regression was fitted with country as random effects.

Secondly, to explore association of each SPI domain to adjusted 30-day mortality, we developed an adjusted logistic regression model for 30-day mortality using patient and operative factors, with country as random effects. Predicted probabilities of 30-day mortality for each patient were summed by hospital and observed-to-expected ratios of outcomes derived, which were converted to adjusted hospital 30-day postoperative mortality by multiplication with the population outcome proportion. Quintiles of hospital risk were formed with intervals defined by groups containing close to equal numbers of patients (rather than hospitals) after ranking by hospital-level risk. The relationship of each SPI domain with an aggregated rating of good at hospital level (i.e., rating four or five) was calculated for both the top and bottom mortality patient quintiles. This determines how many well-performing centres were present in top/bottom quintiles for each SPI domain, allowing a measure of discrimination to understand which hospital factors might be responsible for the variation seen. A difference of 10% or more between the best- and worst-performing hospitals was considered clinically meaningful, and SPI domains meeting this threshold were highlighted. This criterion ensured that the domains with the greatest potential for impact were identified, rather than relying solely on statistical significance, since most differences were statistically significant due to a large sample size.

Thirdly, to isolate the role of preparedness, independent of temporal changes such as in SARS-CoV-2 virulence, we conducted multilevel modelling within Pandemic Period 4 alone. In this analysis we explored risk factors for 30-day postoperative mortality, including vaccination, and hospital-level features, stratified by country income group.

Sensitivity analysis

A restricted cubic spline transformation was used to the continuous representation of SPI to account for potential non-linearity. This was replaced in a final multilevel generalised additive model for Pandemic Periods 1–4.

Ethics approval

These studies were observational, with no changes made to patient pathways. Only routine, anonymised data were collected. In the UK, the study was registered at each site as either a clinical audit or service evaluation. At the lead UK centre (University Hospital Birmingham) it was approved as clinical audit. In other countries, local principal investigators were responsible for contacting competent research ethics committees to obtain local or national approvals in line with applicable regulations, as well as seeking approvals from data protection officers. Informed patient consent was taken unless the need for this was waived by the local research ethics committee or institutional review body.

Role of funding source

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

Results

Overall study characteristics

This study included 31,751 patients with a SARS COV-2 diagnosis undergoing surgery across four pandemic periods from 1589 hospitals in 102 countries. A summary of the patient flow included is presented in Fig. 1. Overall, 23,770 (74.9%) patients were from high income countries, 8783 (27.7%) patients were ≥70 years, and 16,490 (51.9%) were female.

Primary analysis

The overall 30-day mortality was 9.4% (2985/31,751). Mortality was highest in patients aged ≥70 years old (19.1% [1671/8760]), male sex (11.7% [1773/15,201]), ASA grades 3–5 (17.5% [2347/13,401]), and those undergoing emergency surgery (11.7% [2436/20,732]). Baseline patient, disease, and operation characteristics across the pandemic periods are presented in Table 1.

The proportions of patients aged ≥70 years decreased over the course of the pandemic from 42.3% (3171/7502) in Period 1–23.5% (4598/19,588, Table 1) in Period 4. Over the same time periods the proportions of patients with ASA grades 3-5 decreased from 58.9%

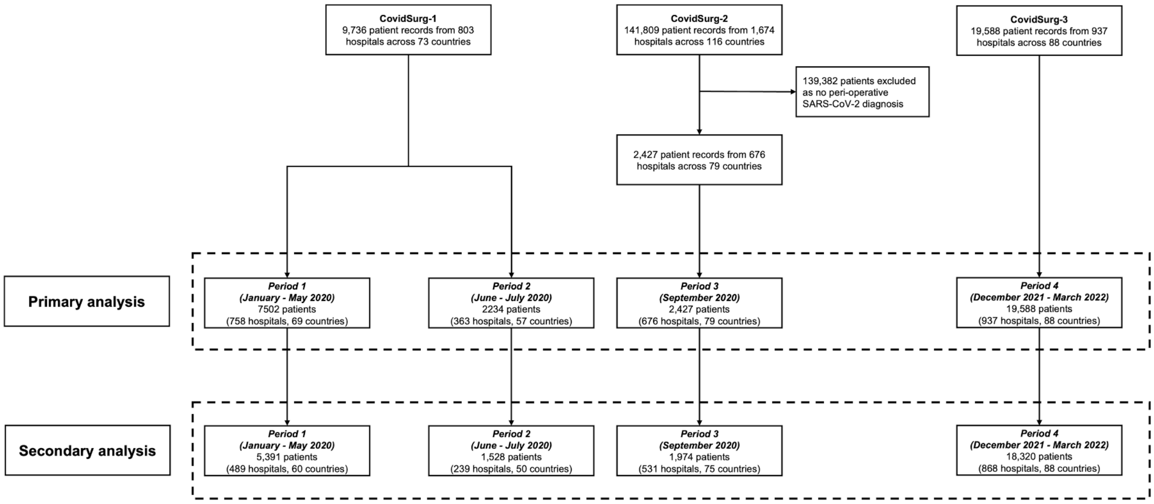


Fig. 1: **Patient inclusion flow chart**.

(4416/7502) to 36.8% (7208/19,588) and the proportions of patients having emergency surgery decreased from 80.7% (6053/7502) to 58.7% (11,506/19,588). Overall 30-day postoperative mortality decreased from Period 1 (18.4% [1378/7502]), Period 2 (9.9% [219/2234]), Period 3 (10.5% [246/2427]), through to Period 4 (5.8% [1132/19,588]), p < 0.001, Appendix p2, Table S1).

In the multilevel model (Appendix p3, Table S2) accounting for hospital and country as random effects, compared with Pandemic Period 1, mortality was lower in Pandemic Period 2 (adjusted OR (aOR) 0.65, 95% confidence interval (CI) 0.53–0.78, p < 0.001), Pandemic Period 3 (aOR 0.60, 95% CI 0.50–0.71, p < 0.001), and Pandemic Period 4 (aOR 0.33, 95% CI 0.30–0.37, p < 0.001, Fig. 2).

Secondary analyses

Secondary analyses explored the association between hospital preparedness and 30-day mortality. These analyses were based on data from hospitals for which SPI ratings were available; this included 27,213 patients across 1230 hospitals in 97 countries. The mean SPI rating was 90.9 (95% CI 90.8–91.1; standard deviation: 14.0).

Firstly, hospitals were categorised by SPI tertile (cut-offs were ≤86 for poorly-prepared, 87–96 for moderately-prepared, and ≥97 for highly-prepared hospitals). Patients undergoing surgery in highly-prepared hospitals were younger, more likely to undergo elective surgery, and more likely to be in high income countries (Table 2). Across all pandemic periods, postoperative mortality was 5.8% (530/9071) in highly-prepared hospitals, 9.4% (857/9071) in moderately-prepared, and 11.2% (1019/9071) in poorly-prepared hospitals. In the multilevel model, compared to poorly-prepared hospitals, moderately-prepared (aOR 0.84, 95% CI 0.75–0.94, p = 0.002) and highly-prepared (OR 0.70, 95% CI 0.62–0.80, p < 0.001) hospitals had lower 30-day mortality (Fig. 3A, Appendix p4, Table S3).

Secondly, the association of each SPI domain with adjusted 30-day mortality was explored. Adjusted 30-day postoperative mortality ranged from 0.1% (8/5473) in quintile 1 (i.e., hospitals with lowest mortality) to 19.7% (1060/5371) in quintile 5 (i.e., hospitals with highest mortality) (Appendix p5, Table S4). Key domains that discriminated between quintile 1 and quintile 5 were patient and procedure prioritisation, ring-fenced theatres, preoperative assessment and formal plans (Fig. 3B).

Thirdly, an adjusted analysis was completed to explore risk factors for 30-day postoperative mortality within Pandemic Period 4 alone. Baseline patient, disease, and operation characteristics for Pandemic Period 4 are presented in the Appendix (p6, Table S5). In the analysis of Pandemic Period 4 data (Appendix p7-8, Table S6, Figure S1), vaccinated patients lower 30-day postoperative mortality than unvaccinated patients (4.9% [603/12,361] versus 7.4% [529/7178], aOR 0.49, CI 0.42–0.57, p < 0.001). Taking in to account SPI scores in the adjusted multilevel model for Period 4 only, compared to poorly-prepared hospitals, moderately-prepared (aOR 0.72, 95% CI 0.60–0.96, p = 0.002) and highly-prepared (aOR 0.66, 95% CI 0.55–0.79, p < 0.001) hospitals had lower 30-day postoperative mortality (Appendix p9-10, Tables S7–S8).

Sensitivity analysis

An analysis of the relationship of SPI as a continuous variable with mortality found that adjusted 30-day postoperative mortality decreased with increasing hospital SPI ratings (Fig. 3C). When stratified by country

	Pandemic period 1	Pandemic period 2	Pandemic period 3	Pandemic period 4	Total	p-value
Total	7502 (23.6)	2234 (7.0)	2427 (7.6)	19,588 (61.7)	31,751	
Age						
<40 years	1496 (19.9)	1020 (45.7)	792 (32.6)	7437 (38.0)	10,745 (33.8)	<0.001
40–49 years	662 (8.8)	273 (12.2)	286 (11.8)	2318 (11.8)	3539 (11.1)	
50–59 years	942 (12.6)	300 (13.4)	339 (14.0)	2504 (12.8)	4085 (12.9)	
60–69 years	1229 (16.4)	276 (12.4)	357 (14.7)	2730 (13.9)	4592 (14.5)	
≥70 years	3171 (42.3)	361 (16.2)	653 (26.9)	4598 (23.5)	8783 (27.7)	
(Missing)	2 (0.0)	4 (0.2)	0 (0.0)	1 (0.0)	7 (0.0)	
Sex						
Male	3852 (51.3)	1163 (52.1)	1150 (47.4)	9079 (46.3)	15,244 (48.0)	<0.001
Female	3640 (48.5)	1066 (47.7)	1277 (52.6)	10,507 (53.6)	16,490 (51.9)	
(Missing)	10 (0.1)	5 (0.2)	0 (0.0)	2 (0.0)	17 (0.1)	
ASA grades						
1	833 (11.1)	541 (24.2)	539 (22.2)	5048 (25.8)	6961 (21.9)	<0.001
2	2203 (29.4)	810 (36.3)	959 (39.5)	7321 (37.4)	11,293 (35.6)	
3–5	4416 (58.9)	876 (39.2)	929 (38.3)	7208 (36.8)	13,429 (42.3)	
(Missing)	50 (0.7)	7 (0.3)	0 (0.0)	11 (0.1)	68 (0.2)	
Revised cardiac risk index score						
0	2240 (29.9)	803 (35.9)	818 (33.7)	7836 (40.0)	11,697 (36.8)	<0.001
1	3324 (44.3)	1042 (46.6)	1102 (45.4)	7899 (40.3)	13,367 (42.1)	
2	1309 (17.4)	292 (13.1)	354 (14.6)	2553 (13.0)	4508 (14.2)	
≥3	622 (8.3)	93 (4.2)	153 (6.3)	1300 (6.6)	2168 (6.8)	
(Missing)	7 (0.1)	4 (0.2)	0 (0.0)	0 (0.0)	11 (0.0)	
Indication of surgery						
Benign	4189 (55.8)	1528 (68.4)	1548 (63.8)	12,710 (64.9)	19,975 (62.9)	<0.001
Cancer	1241 (16.5)	266 (11.9)	425 (17.5)	2910 (14.9)	4842 (15.2)	
Trauma	2059 (27.4)	429 (19.2)	454 (18.7)	3962 (20.2)	6904 (21.7)	
(Missing)	13 (0.2)	11 (0.5)	0 (0.0)	6 (0.0)	30 (0.1)	
Urgency of surgery						
Elective	1446 (19.3)	409 (18.3)	1009 (41.6)	8077 (41.2)	10,941 (34.5)	<0.001
Emergency	6053 (80.7)	1811 (81.1)	1418 (58.4)	11,506 (58.7)	20,788 (65.5)	
(Missing)	3 (0.0)	14 (0.6)	0 (0.0)	5 (0.0)	22 (0.1)	
Grade of surgery						
Minor	2029 (27.0)	722 (32.3)	769 (31.7)	6702 (34.2)	10,222 (32.2)	<0.001
Major	5408 (72.1)	1456 (65.2)	1658 (68.3)	12,881 (65.8)	21,403 (67.4)	
(Missing)	65 (0.9)	56 (2.5)	0 (0.0)	5 (0.0)	126 (0.4)	
Anaesthesia						
General	5506 (73.4)	1542 (69.0)	1705 (70.3)	13,991 (71.4)	22,744 (71.6)	<0.001
Locoregional	1965 (26.2)	647 (29.0)	721 (29.7)	5568 (28.4)	8901 (28.0)	
(Missing)	31 (0.4)	45 (2.0)	1 (0.0)	29 (0.1)	106 (0.3)	
Timing of diagnosis						
Preoperative	3789 (50.5)	1599 (71.6)	926 (38.2)	10,450 (53.3)	16,764 (52.8)	<0.001
Postoperative	3705 (49.4)	612 (27.4)	1501 (61.8)	9090 (46.4)	14,908 (47.0)	
(Missing)	8 (0.1)	23 (1.0)	0 (0.0)	48 (0.2)	79 (0.2)	
Country income group						
High	6654 (88.7)	1399 (62.6)	1419 (58.5)	14,298 (73.0)	23,770 (74.9)	<0.001
Upper middle	581 (7.7)	567 (25.4)	543 (22.4)	3263 (16.7)	4954 (15.6)	
Lower middle or low	267 (3.6)	268 (12.0)	465 (19.2)	2027 (10.3)	3027 (9.5)	

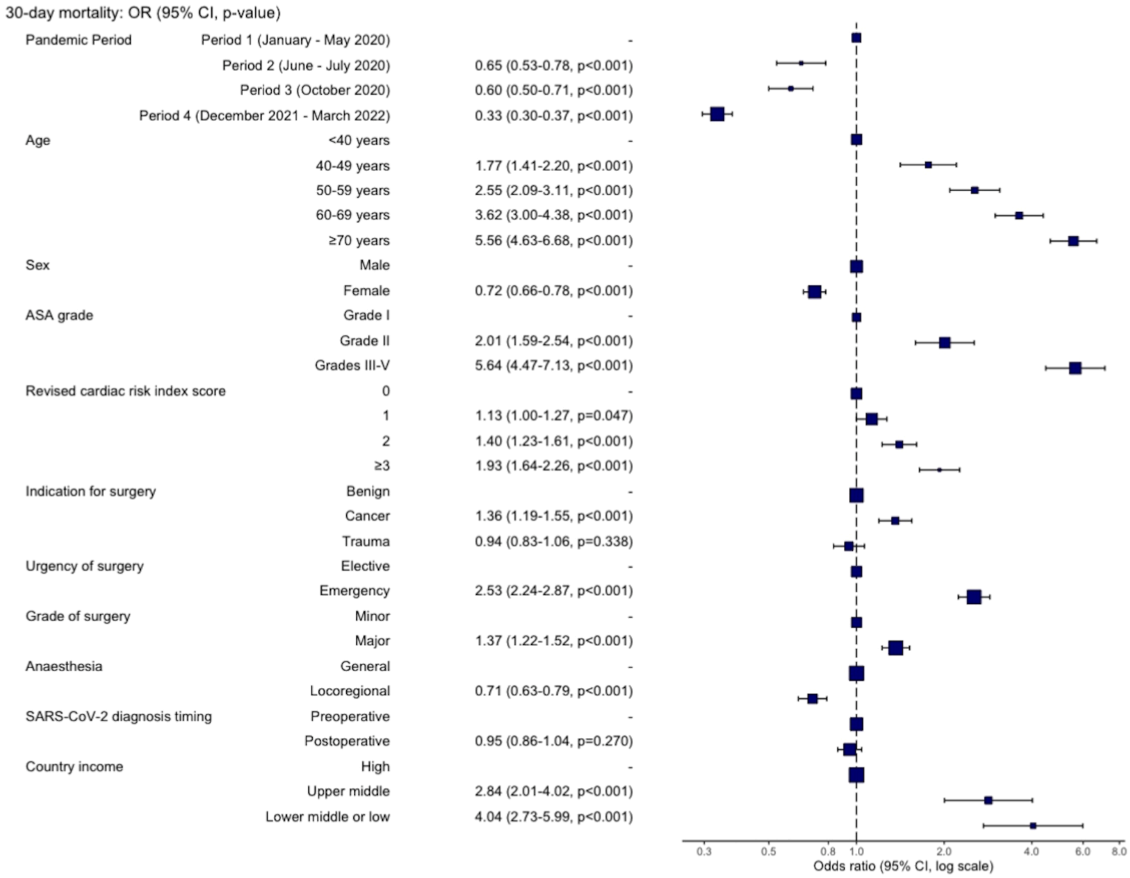
American Society of Anaesthesiologists (ASA) physical status classification grade.

***Table 1:* Patient, disease, and operation characteristics, stratified by pandemic period.**

income group, there was a consistent trend of lower mortality at SPI ≥60 as SPI rating increased (Fig. 3D); the small number of hospitals rated as having SPI <60 means that country-income sub-group results at that SPI rating should be interpretation with caution.

Discussion

This study is unique in tracking global trends in surgical practice and outcomes throughout the COVID-19 pandemic. It has demonstrated a global decrease in postoperative mortality in patients with perioperative



30-day mortality: OR (95% CI, p-value)

Pandemic Period	Period 1 (January - May 2020)	-
	Period 2 (June - July 2020)	0.65 (0.53-0.78, p<0.001)
	Period 3 (October 2020)	0.60 (0.50-0.71, p<0.001)
	Period 4 (December 2021 - March 2022)	0.33 (0.30-0.37, p<0.001)
Age	<40 years	-
	40-49 years	1.77 (1.41-2.20, p<0.001)
	50-59 years	2.55 (2.09-3.11, p<0.001)
	60-69 years	3.62 (3.00-4.38, p<0.001)
	≥70 years	5.56 (4.63-6.68, p<0.001)
Sex	Male	-
	Female	0.72 (0.66-0.78, p<0.001)
ASA grade	Grade I	-
	Grade II	2.01 (1.59-2.54, p<0.001)
	Grades III-V	5.64 (4.47-7.13, p<0.001)
Revised cardiac risk index score	0	-
	1	1.13 (1.00-1.27, p=0.047)
	2	1.40 (1.23-1.61, p<0.001)
	≥3	1.93 (1.64-2.26, p<0.001)
Indication for surgery	Benign	-
	Cancer	1.36 (1.19-1.55, p<0.001)
	Trauma	0.94 (0.83-1.06, p=0.338)
Urgency of surgery	Elective	-
	Emergency	2.53 (2.24-2.87, p<0.001)
Grade of surgery	Minor	-
	Major	1.37 (1.22-1.52, p<0.001)
Anaesthesia	General	-
	Locoregional	0.71 (0.63-0.79, p<0.001)
SARS-CoV-2 diagnosis timing	Preoperative	-
	Postoperative	0.95 (0.86-1.04, p=0.270)
Country income	High	-
	Upper middle	2.84 (2.01-4.02, p<0.001)
	Lower middle or low	4.04 (2.73-5.99, p<0.001)

Fig. 2: **Primary analysis of postoperative mortality across the four pandemic periods**. American Society of Anaesthesiologists (ASA) physical status classification grade. This multilevel logistic regression model included hospital and country as random effects. The full underlying data are presented in the Appendix (p3, Table S2).

SARS-CoV-2 infections during the pandemic. From early-to mid-2020, a shift towards lower-risk patient selection was associated with reduced overall mortality. In 2021, the introduction of SARS-CoV-2 vaccination was associated with a further decrease in odds. However, these two factors do not fully explain the overall reduction in mortality across the pandemic, suggesting that the decreased SARS-CoV-2 virulence and increasing immunity from previous infections may have also contributed. These data support previous modelling of the benefits of prioritisation of SARS-CoV-2 vaccination for high-risk patients planned to undergo elective procedures that cannot be safely delayed, for example, cancer surgery.

The key secondary finding from this study was that postoperative mortality was lower in better prepared hospitals. Several previous studies have evaluated pandemic preparedness at country-level[24,25] or within individual countries,[26–30] but this is the first study to comprehensively evaluate the association between hospital-level preparedness and patient-level outcomes.[24,31] This study indicates a patient benefit to measuring local preparation and strengthening preparedness at a local hospital-level. These findings are consistent across country-income settings indicating the importance of investment in surgical systems across all settings to strengthen future pandemic preparedness.

This study has identified clear actions for hospital leaders, surgical associations, and national policymakers. National-level pandemic-preparedness plans must integrate strategies that enable the continuation elective surgery, ensuring that all healthcare workers are prepared and resourced to maintain elective care. Regular SPI measurement and reporting should be embedded in these plans to guide efforted aimed at strengthening hospital preparedness. However, the implementation of SPI is not dependent on governments, since it is an open-access tool that frontline surgical teams can take ownership of and champion to guide local quality improvement initiatives. Future studies should track SPI globally and identify successful strategies that facilitate its successful implementation.

In future pandemics, hospitals must be prepared and agile so they can rapidly implement and de-

	Poorly-prepared	Moderately-prepared	Highly-prepared	Total	p-value
Total	9071 (33.3)	9071 (33.3)	9071 (33.3)	27,213	
Pandemic period					
Period 1 (Jan–May 2020)	1981 (21.8)	2210 (24.4)	1200 (13.2)	5391 (19.8)	<0.001
Period 2 (Jun–Jul 2020)	502 (5.5)	431 (4.8)	595 (6.6)	1528 (5.6)	
Period 3 (Oct 2020)	883 (9.7)	738 (8.1)	353 (3.9)	1974 (7.3)	
Period 4 (Dec 2021–Mar 2022)	5705 (62.9)	5692 (62.7)	6923 (76.3)	18,320 (67.3)	
Age					
<40 years	3060 (33.7)	2865 (31.6)	3365 (37.1)	9290 (34.1)	<0.001
40–49 years	977 (10.8)	997 (11.0)	1081 (11.9)	3055 (11.2)	
50–59 years	1128 (12.4)	1106 (12.2)	1225 (13.5)	3459 (12.7)	
60–69 years	1280 (14.1)	1363 (15.0)	1296 (14.3)	3939 (14.5)	
≥70 years	2623 (28.9)	2738 (30.2)	2104 (23.2)	7465 (27.4)	
(Missing)	3 (0.0)	2 (0.0)	0 (0.0)	5 (0.0)	
Sex					
Male	4324 (47.7)	4369 (48.2)	4316 (47.6)	13,009 (47.8)	0.712
Female	4738 (52.2)	4700 (51.8)	4752 (52.4)	14,190 (52.1)	
(Missing)	9 (0.1)	2 (0.0)	3 (0.0)	14 (0.1)	
ASA grades					
1	2220 (24.5)	1844 (20.3)	2127 (23.4)	6191 (22.8)	<0.001
2	3204 (35.3)	3340 (36.8)	3212 (35.4)	9756 (35.9)	
3–5	3615 (39.9)	3877 (42.7)	3717 (41.0)	11,209 (41.2)	
(Missing)	32 (0.4)	10 (0.1)	15 (0.2)	57 (0.2)	
Revised cardiac risk index score					
0	3291 (36.3)	3176 (35.0)	3664 (40.4)	10,131 (37.2)	<0.001
1	3802 (41.9)	3955 (43.6)	3661 (40.4)	11,418 (42.0)	
2	1354 (14.9)	1354 (14.9)	1141 (12.6)	3849 (14.1)	
≥3	618 (6.8)	582 (6.4)	605 (6.7)	1805 (6.6)	
(Missing)	6 (0.1)	4 (0.0)	0 (0.0)	10 (0.0)	
Indication for surgery					
Benign	5683 (62.7)	5444 (60.0)	5870 (64.7)	16,997 (62.5)	<0.001
Cancer	1376 (15.2)	1466 (16.2)	1448 (16.0)	4290 (15.8)	
Trauma	2002 (22.1)	2154 (23.7)	1751 (19.3)	5907 (21.7)	
(Missing)	10 (0.1)	7 (0.1)	2 (0.0)	19 (0.1)	
Urgency of surgery					
Elective	3005 (33.1)	3224 (35.5)	3585 (39.5)	9814 (36.1)	<0.001
Emergency	6057 (66.8)	5843 (64.4)	5484 (60.5)	17,384 (63.9)	
(Missing)	9 (0.1)	4 (0.0)	2 (0.0)	15 (0.1)	
Grade of surgery					
Minor	2925 (32.2)	2817 (31.1)	2977 (32.8)	8719 (32.0)	0.037
Major	6108 (67.3)	6227 (68.6)	6078 (67.0)	18,413 (67.7)	
(Missing)	38 (0.4)	27 (0.3)	16 (0.2)	81 (0.3)	
Anaesthesia					
General	6320 (69.7)	6521 (71.9)	6568 (72.4)	19,409 (71.3)	<0.001
Locoregional	2720 (30.0)	2529 (27.9)	2491 (27.5)	7740 (28.4)	
(Missing)	31 (0.3)	21 (0.2)	12 (0.1)	64 (0.2)	
SARS-CoV-2 diagnosis timing					
Preoperative	4732 (52.2)	4403 (48.5)	5016 (55.3)	14,151 (52.0)	<0.001
Postoperative	4279 (47.2)	4662 (51.4)	4053 (44.7)	12,994 (47.7)	
(Missing)	60 (0.7)	6 (0.1)	2 (0.0)	68 (0.2)	
30-day mortality					
No	8028 (88.5)	8195 (90.3)	8524 (94.0)	24,747 (90.9)	<0.001
Yes	1019 (11.2)	857 (9.4)	530 (5.8)	2406 (8.8)	
(Missing)	24 (0.3)	19 (0.2)	17 (0.2)	60 (0.2)	
Country income group					
High	6030 (66.5)	7067 (77.9)	7297 (80.4)	20,394 (74.9)	<0.001
Upper middle	1726 (19.0)	1238 (13.6)	1078 (11.9)	4042 (14.9)	
Lower middle or low	1315 (14.5)	766 (8.4)	696 (7.7)	2777 (10.2)	

American Society of Anaesthesiologists (ASA) physical status classification grade.

Table 2: **Baseline patient, disease, and operation characteristics for Pandemic Periods 1–4, stratified by hospital-level Surgical Preparedness Index.**

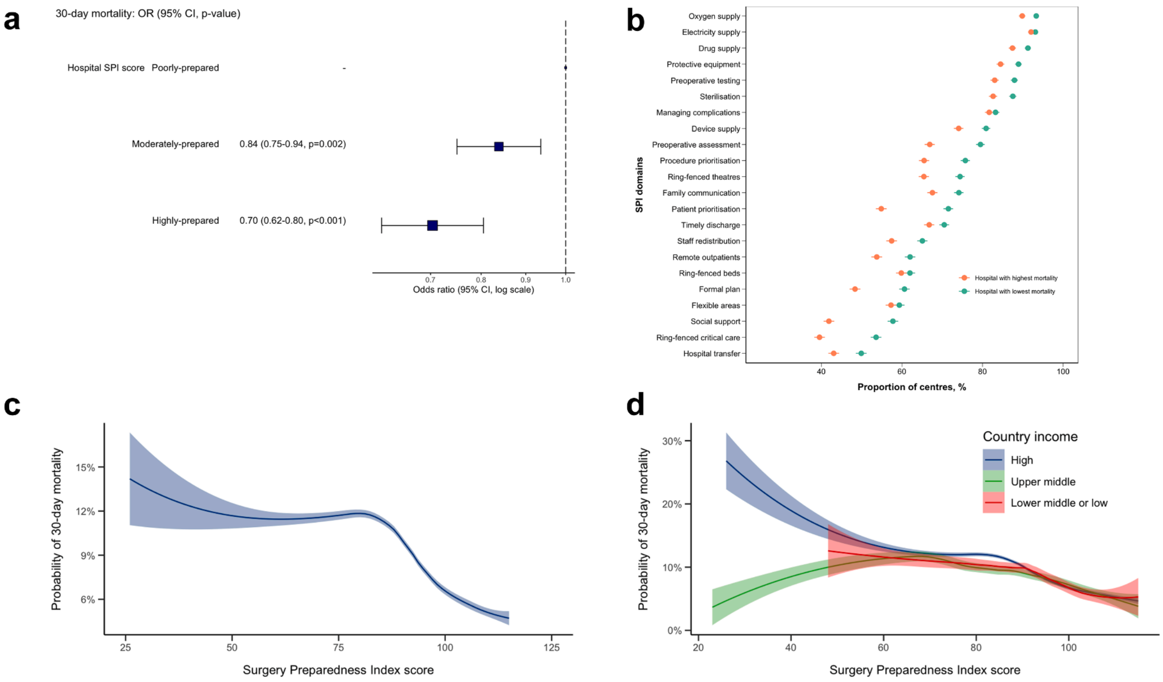


Fig. 3: **Secondary analysis of association between Surgical Preparedness Index and 30-day postoperative mortality**. This figure shows the findings of multilevel models exploring association between the Surgical Preparedness Index (SPI) and 30-day postoperative mortality. In all models, country was incorporated as random effects and the following variables as fixed effects: pandemic periods, country income group, age, sex, ASA grade, revised cardiac risk index, indication for surgery, urgency of surgery, grade of surgery, anaesthesia and timing of diagnosis. (a–d) Relationship of SPI in patients across Pandemic Periods 1–4.

implement pandemic protocols. During pandemic surges hospitals should implement measures to keep patients safe including patient prioritisation protocols, vaccination, and infection control measures such as transmission-free pathways. When infection rates fall, they should rapidly de-escalate these measures to reopen to minimise disruption to patient pathways and reduce treatment delays. Decisions on when to de-escalate infection control measures should be informed by hospital-level preparedness, as well as broader epidemiological considerations such as infection virulence and vaccine availability. These decisions must also be context-specific, taking into account local priorities, healthcare capacity, and resource availability.

Hospital-level preparedness should be regularly assessed using SPI to drive continuous improvement by identifying local context-specific priorities for whole hospital strengthening. It is unlikely that improvement in a single SPI domain is sufficient to substantially alter performance in a pandemic, rather there should be a focus on consistent, incremental improvements across all domains. Moreover, given surgical systems extensively supported the wider pandemic response, through medical gases, supply chains, and critical care facilities, investment in surgery is likely to be effective in both strengthening wider hospital and community resilience across multiple disease pathways, and boosting health system capacity and performance outside of crisis periods, for example by increasing access to medical gasses, diagnostics, and secure energy.

The major strength of this study is the pooled data from 1582 hospitals across three sequential cohort studies and highlighted the importance of rapid, prospective research to inform surgical care during crises such as pandemics. By harnessing data across 102 countries, the study identified many common issues across different hospitals by country income groups, demonstrating the need to invest in hospital preparedness and research infrastructure to support this. However, there are important limitations. Firstly, some patients with perioperative SARS-CoV-2 infection may have been missed if they were not tested as part of their routine clinical care or if their test returned a false negative result. In addition, it was not feasible in this pragmatic global study to collect data the SARS-CoV-2 variant for each patient. Secondly, there may be biases with the self-reported SPI ratings. However, SPI has been validated and compares well with other national-level indicators.[20] Thirdly, all variables were captured as categorical, including age, limiting the opportunity to explore non-linear relationships of age. Despite this, use of these age categories was well-reported from previous studies, justifying its use in the present study. We used logistic regression to estimate odds ratios, which may overstate relative risks when outcomes are common, so the magnitude of effect should be interpreted with caution; alternative models such as Poisson regression may yield more accurate risk estimates. Finally, there may be residual confounding in the association between SPI and postoperative mortality, for example, as we have not fully accounted for all patients that might effect clinician decision making, nor hospital funding and diagnostic and acute care capacity.

Our findings have significant implications global pandemic preparedness policymaking,[32,33] including by governments, the WHO, and major health funders such as the Gates Foundation. Firstly, given its critical role in life-saving care such as cancer treatment, children's health, and women's health, surgical planning must be embedded into broader health system pandemic planning at regional, national, and global levels. A particular focus should be on the interdependency between surgical care and primary health systems. Secondly, to avoid the extensive wider health impacts of lockdowns[11,20] in the future, significant investment is needed to increase surgical and hospital system preparedness. It is estimated US$43 billion per year is needed to develop and sustain health emergency preparedness across 139 low- and middle-income countries,[32] but hospitals are largely neglected in these calculations. It is essential to address the neglected needs of hospital systems in future funding rounds.

Finally, this study evaluated the importance of pandemic preparedness for maintaining safe surgical care, surgical care can be impacted by a broader range of health security risks, including extreme weather events and natural disasters, conflicts, terrorism, and other mass casualty incidents.[9] Further validation of SPI is required to support its use when preparing for these broader risks. Nonetheless hospitals are critical national infrastructure[34] with an integral role to crisis response; surgical services underpin this both by providing emergency and trauma care and supporting the wider hospital response. Embedding hospital-level preparedness into national emergency planning would create robust systems capable of responding to diverse health emergencies.

Contributors

The writing group (DN, SKK, RA, WA, EA, RBC, ME, DG, JCG, AI, KJ, HK, BK, HL, SL, OAO, FP, MP, PP, MDS, JFFS, GT, AB) and the statistical analysis groups (AB, BK, SKK, DN, OAO) all contributed to data curation and interpretation. The writing group contributed to writing and critical revision of the manuscript. The steering group, national leads and dissemination committee contributed to study conception, protocol development, study delivery, and management. The collaborators contributed to data collection and study governance across included sites. The statistical analysis group had full access to the data in this study, accessed and verified the data. The writing committee had final responsibility for the decision to submit for publication. All collaborating authors are shown in the appendix.

Data sharing statement

Data sharing requests will be considered by the writing group upon written request to the corresponding author. De-identified participant data and/or other pre-specified data will be available, subject to a written proposal and an agreed data sharing agreement.

Declaration of interests

All authors declare no conflict of interest

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanepe.2025.101566.

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