Elective surgery system strengthening: development, measurement, and validation of the surgical preparedness index across 1632 hospitals in 119 countries

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See Online for appendix

Summary

Background The 2015 *Lancet* Commission on global surgery identified surgery and anaesthesia as indispensable parts of holistic health-care systems. However, COVID-19 exposed the fragility of planned surgical services around the world, which have also been neglected in pandemic recovery planning. This study aimed to develop and validate a novel index to support local elective surgical system strengthening and address growing backlogs.

Methods First, we performed an international consultation through a four-stage consensus process to develop a multidomain index for hospital-level assessment (surgical preparedness index; SPI). Second, we measured surgical preparedness across a global network of hospitals in high-income countries (HICs), middle-income countries (MICs), and low-income countries (LICs) to explore the distribution of the SPI at national, subnational, and hospital levels. Finally, using COVID-19 as an example of an external system shock, we compared hospitals' SPI to their planned surgical volume ratio (SVR; ie, operations for which the decision for surgery was made before hospital admission), calculated as the ratio of the observed surgical volume over a 1-month assessment period between June 6 and Aug 5, 2021, against the expected surgical volume based on hospital administrative data from the same period in 2019 (ie, a pre-pandemic baseline). A linear mixed-effects regression model was used to determine the effect of increasing SPI score.

Findings In the first phase, from a longlist of 103 candidate indicators, 23 were prioritised as core indicators of elective surgical system preparedness by 69 clinicians (23 [33%] women; 46 [67%] men; 41 from HICs, 22 from MICs, and six from LICs) from 32 countries. The multidomain SPI included 11 indicators on facilities and consumables, two on staffing, two on prioritisation, and eight on systems. Hospitals were scored from 23 (least prepared) to 115 points (most prepared). In the second phase, surgical preparedness was measured in 1632 hospitals by 4714 clinicians from 119 countries. 745 (45·6%) of 1632 hospitals were in MICs or LICs. The mean SPI score was 84·5 (95% CI 84·1–84·9), which varied between HIC (88·5 [89·0–88·0]), MIC (81·8 [82·5–81·1]), and LIC (66·8 [64·9–68·7]) settings. In the third phase, 1217 (74·6%) hospitals did not maintain their expected SVR during the COVID-19 pandemic, of which 625 (51·4%) were from HIC, 538 (44·2%) from MIC, and 54 (4·4%) from LIC settings. In the mixed-effects model, a 10-point increase in SPI corresponded to a 3·6% (95% CI 3·0–4·1; p<0·0001) increase in SVR. This was consistent in HIC (4·8% [4·1–5·5]; p<0·0001), MIC (2·8 [2·0–3·7]; p<0·0001), and LIC (3·8 [1·3–6·7%]; p<0·0001) settings.

Interpretation The SPI contains 23 indicators that are globally applicable, relevant across different system stressors, vary at a subnational level, and are collectable by front-line teams. In the case study of COVID-19, a higher SPI was associated with an increased planned surgical volume ratio independent of country income status, COVID-19 burden, and hospital type. Hospitals should perform annual self-assessment of their surgical preparedness to identify areas that can be improved, create resilience in local surgical systems, and upscale capacity to address elective surgery backlogs.

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Introduction

The COVID-19 pandemic highlighted the fragility of elective surgical services around the world, yet global surgery risks being neglected in pandemic recovery planning.[1–3] At the start of 2022 an estimated 200 million patients worldwide were awaiting surgery.[1,2] For time-critical conditions, such as cancer, one in seven patients did not have their planned surgery during SARS-CoV-2 outbreaks and many more had substantial delays to their care.[3] Some patients might never have accessed the surgery they required, with high associated disability and millions of years of healthy life lost.[4,5] With the existing challenges in providing accessible and safe surgical systems in low-income countries (LICs) and middle-income countries (MICs) identified by the 2015 *Lancet* Commission on global surgery, health systems and hospitals with less funding for infrastructure, staffing and equipment were the worst affected, with

Research in context

Evidence before this study

The 2015 *Lancet* Commission on global surgery identified surgery and anaesthesia as an indivisible component of holistic health systems. The COVID-19 pandemic has revealed ongoing fragility in surgery and anaesthesia systems, with more than 200 million patients currently awaiting their planned procedures.

We searched PubMed and Embase from the inception of each database to March 4, 2022, without date limits for indices, frameworks, or guidelines able to assess a hospital or surgical system's ability to deliver planned surgery and anaesthesia during periods of external system stress. Planned surgery included all operations done when a decision for surgery was made before hospital admission, whether this was elective or expedited. We used search terms related to "preparedness", "resilience", "pandemic", or "system stress" in combination with "surgery", "anaesthesia", "surgical systems", "procedures", or "non-communicable disease". External system stressors included airborne pandemics (eg, SARS-CoV-2), non-airborne disease (eg, Ebola virus), and other system stressors (eg, natural disasters, mass trauma, warfare, political instability, and extreme weather events). We identified 15 indices and six frameworks for assessing whole-health system preparedness, but none were specific to surgery nor were they validated against a measure of planned surgical volume. We also identified three tools to quantify essential surgical capacity: WHO Situational Assessment Tool, PIPES Tool, and Ethiopian Hospital Assessment Tool. However, these were not designed to assess preparedness and are complex to complete. Together, this shows that the features of prepared surgery and anaesthesia systems are not yet well understood or properly implemented.

Added value of this study

The Surgical Preparedness Index (SPI) is the first tool that specifically assesses elective surgery and anaesthesia system preparedness. We engaged a diverse, international, and multidisciplinary community to identify and prioritise features of prepared surgery and anaesthesia systems that were relevant across a wide variety of external system shocks. We prioritised 23 globally relevant indicators of surgical preparedness across four domains (facilities, staffing, prioritisation, and processes). The SPI was then measured across a range of hospitals and settings showing significant variability in preparedness between hospitals, regions, and countries. During the COVID-19 pandemic, a pressing and globally relevant example of a system stressor, three-quarters of hospitals reported a reduction in planned surgical volume. The SPI score was shown to be strongly associated with a hospital's ability to continue planned surgery, validating the concept of preparedness in reducing surgical cancellations, with a significant and measurable effect. This relationship was consistent across different types of hospital and health systems, suggesting that SPI measurement was generalisable across contexts.

Implications of all the available evidence

The COVID-19 pandemic highlighted the fragility of surgical services around the world, yet surgery risks being neglected in pandemic recovery planning. Without effective, integrated surgical and anaesthesia systems, non-communicable diseases cannot be effectively treated and community health declines, meaning Sustainable Development Goal 3 cannot be met. Application of the SPI can identify areas for policy change, advocacy, and investment at subnational and local levels. Hospitals should urgently implement annual SPI assessment and create local action plans to strengthen planned surgical services, thus supporting whole-health system resilience. Longitudinal assessment of surgical preparedness can now be incorporated into national surgical, obstetric, and anaesthesia planning and considered an essential indicator of surgical system strength. Future work is required to test the SPI in low-income countries (4·3% of included hospitals).

whole-societal health, economic, social, and political consequences.[3,6] The backlog of patients awaiting planned procedures is now one of the most pressing challenges to global health for the next 10 years.

The SARS-CoV-2 pandemic presented an unprecedented stress on global health systems. Many surgery and anaesthesia services changed their processes for patient selection and reduced their volume of planned procedures, reflecting the high risk to patients planned to receive surgery of perioperative SARS-CoV-2 infection.[7] Different models of care have been proposed to support safe upscaling of planned surgical volume during pandemic recovery.[8,9] However, shared global learning about the best methods to improve preparedness of surgical systems has not been done. Surgical capacity urgently needs to be upscaled to address growing backlogs of patients waiting for their planned procedures and improve preparedness for future system shocks. Solutions need to be identified for infrastructure, staffing, and care pathways that can be applied flexibly across different health systems.[10] COVID-19 (an airborne pandemic) has been just one form of external stress on health systems, but provides an important learning opportunity for surgical providers and policy makers to strengthen surgical preparedness ahead of future system shocks.

Although several indices of health system preparedness and surgical capacity have been proposed, these were not designed to assess preparedness of surgery and anaesthesia services nor have they been validated against a measure of surgical capacity.[11–13] Whole-health system preparedness indicators are often not applicable to surgery, and surgical capacity indicators (eg, the WHO Situational Assessment Tool, PIPES Tool, and Ethiopian Hospital Assessment Tool) are not designed to dynamically assess the response of services to external system pressure and are too complex for everyday use. This study describes the development and validation of a multinational surgical preparedness index (SPI) and framework to support elective surgery and anaesthesia services, strengthening them against future external system shocks.

Methods

This study was done in three phases (figure 1). First, index development. An international consultation was done with a Delphi consensus methodology to develop hospital-level preparedness indicators to support surgical service strengthening. For the purposes of this study, preparedness was defined as the ability of a hospital to maintain capacity for planned surgery during periods of external system shock. Planned surgery was defined as any operation for which the decision for surgery was made before the hospital admission during which the operation took place. Second, measurement of surgical preparedness. A cross-sectional hospital assessment study was done to assess the distribution of the total SPI score at national, subnational, and hospital levels. Third, validation of the multidomain SPI against the observed versus expected elective surgical volume during the COVID-19 pandemic; this was used as a contemporaneous example of a globally relevant system stressor.

Phase 1: development of the SPI

The international consultation was done with a diverse, multidisciplinary, expert index development group. This

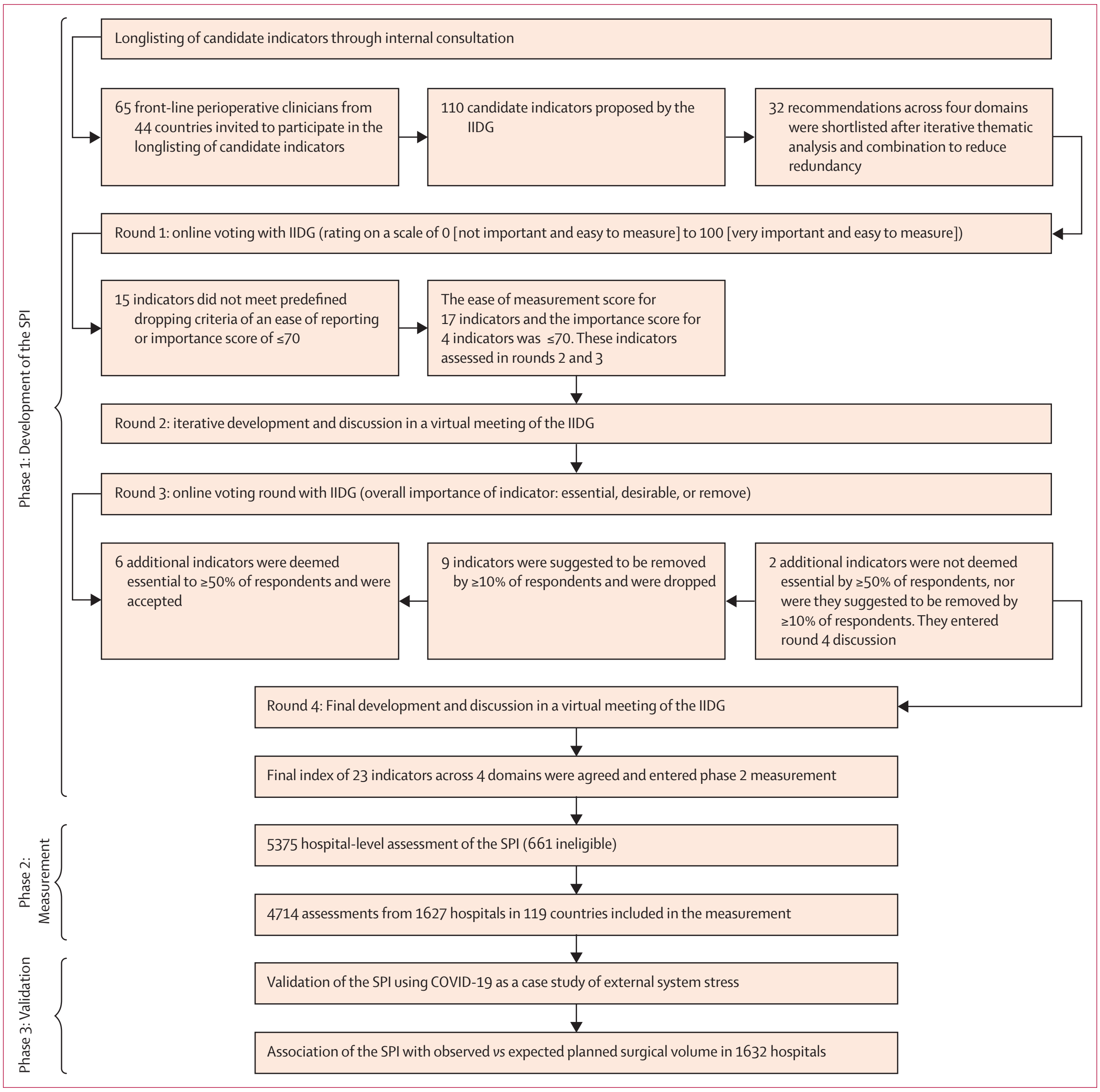

Figure 1: **Overview of study design**
IIDG=international guideline development group. SPI=surgical preparedness index.

included surgeons, anaesthetists, critical-care doctors, nurses, and hospital managers involved in the delivery of planned surgical care across high-income country (HIC), MIC, and LIC settings. The range of people included across care roles and income setting was designed to provide breadth of perspectives during consensus rounds and fulfils typical sample size requirements for Delphi methodologies.[14] A four-stage Delphi process was done within the development group to prioritise hospital-level SPIs. Consensus definitions were set a priori, and the process was done in accordance with best practice recommendations: (1) the expertise matrix was predefined, inclusive, and generalisable; (2) dropping rules were predefined; (3) a limit of two voting and two face-to-face rounds was prespecified; and (4) frequent reminders were sent to respondents to maximise the retention rate.[15] The full methodology for the consultation process is described in the appendix (pp 70–73).

To explore the relevance of the surgical preparedness indicators across other external system shocks, we used a consensus ratings exercise with eight international development group members (two from high-income countries [HICs], four from MICs, and two from LICs). We defined five different external shocks: airborne pandemic, non-airborne pandemic, warfare and political instability, natural disasters, and seasonal pressures. Independent members were asked to rate the relevance (high, moderate, or low) of each indicator in their local context. Inter-rater reliability was estimated using intraclass correlation coefficient (ICC[1k]; one-way random effects, average of k raters) presented with 95% CIs.

Phase 2: preparedness of global surgery and anaesthesia systems

A hospital-level assessment of the SPI was done between June 6 and Aug 5, 2021, and data were recorded by local assessors on a centralised, encrypted Research Electronic Data Capture server hosted by the University of Birmingham, Birmingham, UK.[16] COVIDSurg is a network of more than 15 000 front-line clinicians from the National Institute for Health Research (NIHR) Global Health Research Unit on Global Surgery focused on supporting data-driven decision making in perioperative care.[7] The network facilitated distribution of the SPI assessment was sent to local clinicians and managers to complete for their hospital. Collaborators were encouraged to identify other colleagues to complete multiple assessments of the same hospital to evaluate inter-rater reliability. Any centre worldwide providing planned surgery was eligible to participate. Any postgraduate clinician or manager involved in perioperative care from any specialty background in these centres was eligible to participate. Clinicians without a temporary or permanent contract (ie, locum doctors or equivalent) and medical students were not eligible to participate.

Features of hospital assessors and hospitals were summarised overall and by country income group. To promote application and interpretation of the SPI in clinical practice, we calculated global, regional, and national distributions of SPI. We also disaggregated by hospital type, country income, COVID-19 burden, and country. Where multiple assessments were made of the same hospital, the mean was calculated first by indicator, then an overall mean index score was calculated as an aggregate mean of these means. Results presented across subgroups were calculated as the mean of hospitals' mean SPI scores in each group and presented with a 95% CI. High fidelity centre-level SPI data were presented online on a Shiny (Boston, MA, USA) application hosted on an Argonaut server at the University of Edinburgh, Edinburgh, UK. The inter-rater reliability of SPI assessment was estimated again using the ICC(1k) with 95% CIs.[17]

We explored the relationship between national mean SPI scores and four relevant global health indicators using generalised additive modelling fitted with a penalised cubic spline (with shrinkage). The four selected indicators were: (1) the UN's Human Development Index, which is a composite index of life expectancy, education, and per capita income (a higher Human Development Index score indicates greater development); (2) global health security index, which is an assessment of global health security capabilities (ie, a measure of whole health-system resilience) from the Johns Hopkins Center for Health Security, Baltimore, MD, USA, the Nuclear Threat Initiative (Washington DC, USA), and the Economist Intelligence Unit (London, UK; a high global health security score indicates a more resilient health system); (3) the WHO Universal Health Coverage (UHC) service coverage index, which combines 14 tracer indicators of service coverage into a single summary measure (a higher UHC index indicates greater coverage); and (4) Gini coefficient, which is a measure of population wealth inequality (a Gini coefficient of 0 expresses perfect equality; a coefficient of 1 indicates maximal inequality). Analyses were done with R Studio (version 4.1.1) packages: tidyverse, finalfit, psych, and ggplot2.

Phase 3: validation of the SPI using planned surgical volume during COVID-19

To evaluate the criterion validity of the SPI, we compared a hospital's self-assessed SPI score with its ability to maintain planned surgery capacity. This was estimated using the observed to expected planned surgical volume ratio (SVR), calculated as the ratio of each hospital's observed planned surgical volume over a 1-month assessment period against the expected planned surgical volume based on data from the same month in 2019 (the prepandemic baseline) and expressed as a percentage. Case volume data were measured from routinely collected hospital administrative data, such as theatre logbooks and electronic health-care records. A planned surgery case was defined as any planned admission for a procedure done by a surgeon in an operating theatre under general, regional, or local anaesthesia. This included procedures classified as either elective or expedited in the National Confidential Enquiry into Patient Outcome and Death classification system, but excluded urgent and immediate surgery.[18] Patients undergoing surgery for any indication were eligible for inclusion, including benign disease, cancer, trauma, or obstetrics. This included day-case procedures (ie, discharged same date as operation).

Analyses were done using R Studio packages tidyverse, finalfit, lmer, and ggplot2. A complete-case analysis was preplanned if missing data were both missing at random and in a low number of samples (<5%).[19] In the prestudy protocol, we planned to impute missing data using multiple imputation by chained equations based on a missing at random or missing completely at random assumption if data missingness was more than 5%. Centres with no current planned surgery volume estimate were excluded from analyses. Generalised additive models were fitted using a penalised cubic spline (with shrinkage). Models were initially fitted with a basis dimension of 10 (k). Model fit was checked using residual plots, convergence confirmed, and basis dimension choice checked. If per group estimated degrees of freedom approached basis choice minus one (k–1), then the basis dimension was increased. The link function was identify. A random-error distribution was assumed and checked on residual plots as above. To explore whether this association could be explained by confounding we created a mixed-effects linear regression model with country included as a random effect (normal distribution). We checked assumptions by exploring normality and homogeneity of variance of residuals and linearity of quantitative predictors.

Model coefficients were adjusted for predefined centre-level and country-level confounders that were identified through a scoping review of published literature and considered a priori by the international development group as likely to be clinically and causally linked to both exposure and outcome. A proposed casual model was presented in a directed acyclic graph. Covariables included country income—defined according to World Bank 2018 definitions and classified as HIC, MIC (including both upper-middle and lower-middle classifications), or LIC on the basis of annual gross domestic product per capita (US$); hospital funding (public, private, or mixed public and private); surgical service provision at the facility (planned only versus planned and unplanned); hospital location (defined by the assessor as primarily an urban, rural, or mixed urban and rural area); number of hospital beds (<50, 50–99, 100–199, 200–499, 500–999, or ≥1000); and country COVID-19 burden (low, moderate, or high) at the time of SPI assessment. The Oxford COVID-19 Government Response Tracker (OxCGRT) was used as a surrogate of the overall COVID-19 burden on a local health system at the time of the SPI assessment. The OxCGRT is a composite of 19 indicators, including measures and behavioural interventions associated with containment and closure, economic response, and health systems with an overall score range between 0 (no restrictions) and 100 (most stringent restrictions). It has been validated for use globally by showing associations with planned surgical volume,[3] population SARS-CoV-2 infection rates, and Google mobile phone mobility data.[20] OxCGRT cutpoint scores used in previous work based on comparisons of index scores and national policy sources were used.[3] Each hospital was given a classification based on the country's status at the time of assessment: low COVID-19 burden (index <20), moderate COVID-19 burden (20–60), and high COVID-19 burden (>60). The OxCGRT was preferentially used instead of SARS-CoV-2 case notification rates because of global differences in access to testing and

Panel: Summary of surgical preparedness index

Hospitals were assessed for each indicator by assessors, scored from 1 (very weak) to 5 (very strong) with an overall summary surgical preparedness index score calculated between 23 and 115. A full description of each indicator to support hospital assessment is provided in the appendix (pp 1–2).

Facilities and consumables

1. Availability of reserved planned surgery theatres (ring-fenced theatres)
2. Availability of reserved planned surgery beds (ring-fenced beds)
3. Availability of reserved critical care beds for planned surgery (ring-fenced critical care)
4. Flexibility to rearrange hospital areas to provide a segregated pathway for planned surgery (flexible areas)
5. Access to diagnostics and interventions to identify and treat surgical complications (managing complications)
6. Reliable supply of electricity (electricity supply)
7. Reliable supply of supplementary oxygen (oxygen supply)
8. Reliable supply and management of essential perioperative drugs (drug supply)
9. Reliable supply and management of devices and implants (device supply)
10. Sufficient surgical instrument and local sterilisation processes (sterilisation)
11. Availability of protective measures for theatre teams (protective equipment)

Staffing

12. Ability to redistribute staff within and between hospitals to maintain capacity (staff redistribution)
13. Availability of reserved teams to provide planned surgical care (ring-fenced teams)

Prioritisation

14. Cross-specialty patient prioritisation for surgery (patient prioritisation)
15. Ability to identify and cancel procedures of limited clinical value (procedure prioritisation)

Systems

16. Formal operational plan to continue planned surgery during external system shocks (formal plan)
17. Ability to do preoperative assessment in the community (preoperative assessment)
18. Access to routine preoperative testing for endemic and epidemic diseases (preoperative testing)
19. Ability to transfer patients to another hospital with greater capacity (hospital transfer)
20. Ability to facilitate timely discharges (timely discharge)
21. Social support system to facilitate safe discharge (social support)
22. Capacity to use telephone or video calls for outpatient appointments (remote outpatient appointments)
23. Capacity and capability to communicate with family members (family communication)

reporting.[21,22] Subgroup analyses were presented by country income, COVID-19 burden, hospital financing, and hospital location, presented in cubic spline curves and with β coefficients generated in mixed-effects models.

Role of the funding source

The funders had no role in study design or writing of this report. The views expressed are those of the authors and not necessarily those of the National Health Service, the NIHR or the UK Department of Health and Social Care.

+ High relevance
– Moderate relevance
× Low relevance

	Airborne pandemic	Non-airborne pandemic	Warfare and political instability	Natural disaster (eg, flood and hurricane)	Seasonal pressures (eg, winter and heatwaves)
Facilities and consumables					
Ring-fenced theatres	+	+	+	+	+
Ring-fenced beds	+	+	+	+	+
Ring-fenced critical care	+	+	+	+	+
Flexible areas	+	+	–	–	–
Managing complications	+	+	+	+	+
Electricity supply	+	+	+	+	+
Oxygen supply	+	+	+	+	+
Drug supply	+	+	+	+	+
Device supply	+	+	+	+	+
Sterilisation	+	+	+	+	+
Protective equipment	+	+	+	–	–
Staffing					
Staff redistribution	+	+	+	+	+
Ring-fenced teams	+	+	+	+	+
Prioritisation					
Patient prioritisation	+	+	+	+	+
Procedure prioritisation	+	+	+	+	+
Systems					
Formal plan	+	+	+	+	+
Preoperative assessment	+	+	+	+	+
Preoperative testing	+	+	–	–	–
Hospital transfer	+	+	+	+	+
Timely discharge	+	+	+	+	+
Social support	+	+	+	+	+
Remote outpatients	+	+	+	+	+
Family communication	+	+	+	+	+

Figure 2: **Relevance of the surgical preparedness index to different external shocks**
Independent development group members were asked to rate the relevance of each surgical preparedness indicator following five different external health-care system shocks in their local context.

Results

In phase 1, the international consultation to develop the SPI indicator set involved 69 members (23 [33%] women; 46 [67%] men; 41 from HICs, 22 from MICs, and six from LICs) from 32 countries. This included front-line surgeons, anaesthetists, and critical-care doctors from the COVIDSurg and NIHR Global Health Unit on Global Surgery collaborative networks. Of 110 longlisted candidate indicators, the final index included 23 indicators across four consensus domains: facilities and consumables, staffing, prioritisation, and systems (panel). Detailed descriptions to support hospital assessment are provided in the appendix (pp 1–3). Each indicator was scored using a Likert scale between 1 (very weak) and 5 (very strong). The scores across all 23 indicators were summed to give a total SPI score for a hospital with a range between 23 (least prepared) and 115 (most prepared). A summary of the Delphi voting rounds is presented in figure 1 and full results are reported in the appendix (pp 4–5). All eight independent raters considered the 23 indicators to have high (20 indicators) or moderate (three indicators) relevance to maintaining volume of planned surgery across all five examples of external shocks (figure 2) with high agreement between raters (ICC 0·76 [95% CI 0·59–0·89]).

In phase 2, 5375 hospital-level assessments were completed, of which 503 did not have an identifiable hospital or country or both, 118 did not complete assessment of all indicators, and 40 did not calculate an SVR. Across included facilities, the level of missingness was less than 5% for all indicators; we did a preplanned complete case analysis without imputation. 4714 complete assessments from 1632 hospitals in 119 countries, including 887 (54%) hospitals in 52 (44%) HICs, 675 (41%) hospitals in 56 (47%) MICs, and 70 (4%) hospitals in 11 (9%) LICs, were eligible for analysis in phase 2 and 3.

A summary of included hospitals both overall and by World Bank income group and the number of hospitals and assessments by country are reported in the appendix (pp 6–7). 1217 (74·6%) of 1632 hospitals assessed were public (government) funded, 196 (12·0%) were private hospitals, and 219 (13·4%) were mixed public and private. 1570 (96·2%) hospitals delivered both planned and unplanned surgery. Hospitals in urban, rural, and mixed settings, with a wide range of hospital bed numbers were included in the assessment. The median number of hospitals assessed per country was 6·0 (IQR 2·0–14·5). There was a median of 2·0 (1·0–3·0) assessments per hospital, and 764 (46·8%) hospitals had more than one assessment. In hospitals in which more than one assessment was completed, inter-rater reliability of the SPI was moderate (ICC 0·55 [95% CI 0·53–0·57]). A summary of features of hospital assessors overall and by World Bank income group are reported in the appendix (p 9). The hospital assessors were most commonly

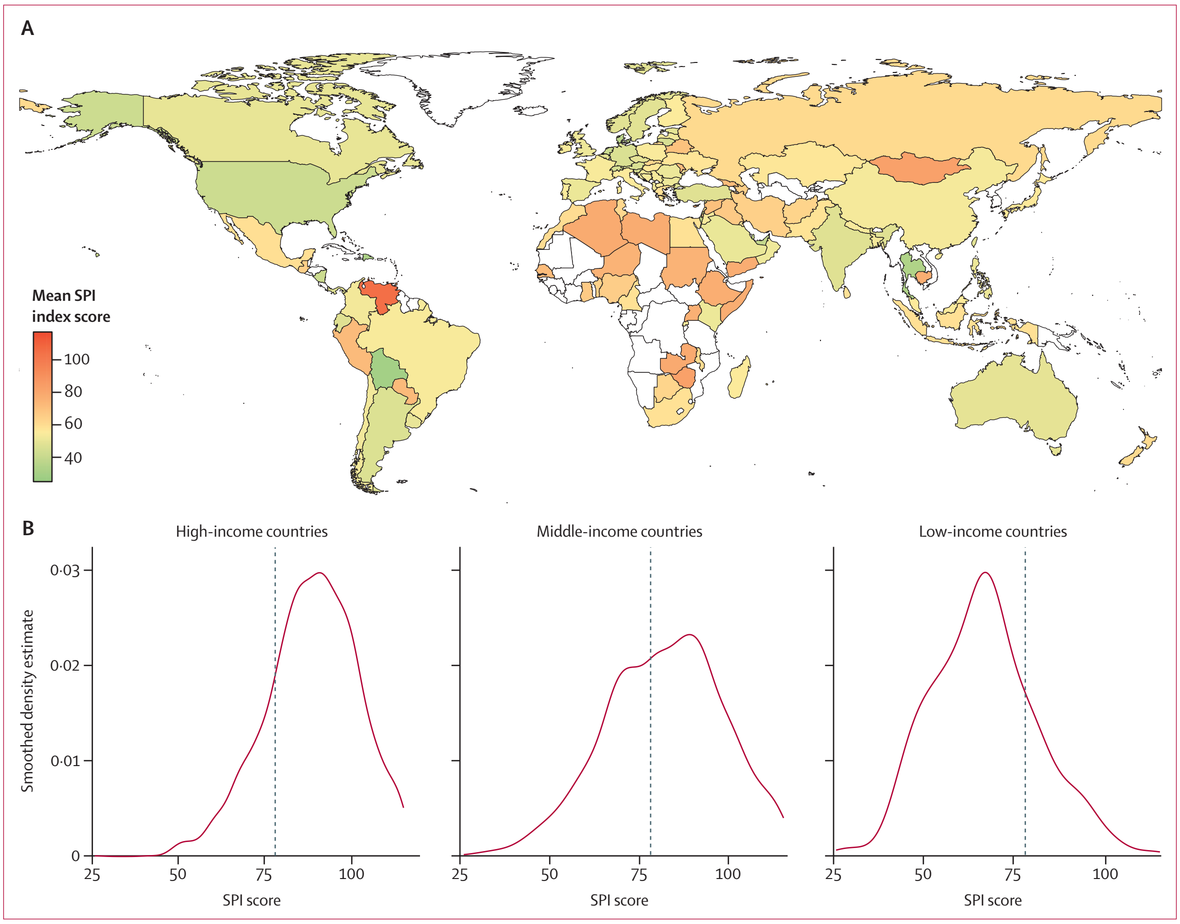

Figure 3: **Geographical distribution of SPI score**

(A) Distribution displayed is centred around the mean value of SPI total score (84·5). Green indicates better prepared surgical systems; red indicates less prepared surgical systems. (B) Distribution of the SPI by country income group. The theoretical score range limits of the SPI were 23–115 points. The lowest mean hospital score was 26 and the highest was 115. These values are displayed at the floor and ceiling values of the x-axis. SPI=surgical preparedness index.

surgeons (2845 [60·4%] of 4714 assessors), although assessments were completed by a range of professionals from across all surgical disciplines. The mean SPI scores per hospital was 84·5 (95% CI 84·1–84·9) out of 115, and global distribution of the SPI are reported in figure 3. Hospital scores ranged from 26 to 115. There was variation in the mean SPI across subgroups: HICs (88·5 [95% CI 89·0–88·0]), MICs (81·8 [82·5–81·1]), and LICs (66·8 [64·9–68·7]); moderate (81·1 [80·4–81·8) and high (87·1 [86·6–87·6) COVID-19 burden areas; public (83·0 [82·5–83·5]) and private or mixed (89·8 [88·9–90·7]) hospitals; and urban (86·1 [85·4–86·8]), rural (77·4 [74·2–80·6]), and mixed (83·7 [83·1–84·3]) settings (appendix p 11).

The mean scores (out of five) for each individual indicator, presented overall and by World Bank income group are reported in figure 4. The highest scored indicators were electricity supply (4·38 [95% CI 4·34–4·41]), oxygen supply (4·33 [4·29–4·36]), and perioperative drugs (4·17 [4·34–4·41]). The lowest scored indicators overall were ring-fenced critical care beds (3·11 [3·07–3·17]), remote outpatient appointments (3·26 [3·21–3·32]), and formal operational plan (3·28 [3·23–3·32]). The biggest differences by indicator were seen in device supply (standardised mean difference between HICs and LICs was –1·80 points), remote outpatients (–1·63), and drug supply (–1·62).

In the country-level analysis, greater surgical preparedness was associated with higher levels of human development, health security, and UHC, and lower levels of wealth inequality (appendix p 12). A suggested framework for assessment of the SPI and targeted, local systems strengthening initiatives is reported in the appendix (p 13), and an online application to support longitudinal evaluation.

For more on the **live hospital SPI assessment tool** see spi.surgery

In phase 3, at the time of assessment, 1217 (74·6%) of 1632 hospitals had an SVR of less than 1, suggesting that they were unable to maintain usual planned surgical volume during COVID-19. Of these 625 (51·4%) hospitals were from HICs, 538 (44·2%) from MICs, and 54 (4·4%) from LICs (appendix pp 14–15). The mean SVR was 79·3% (95% CI 78·1–80·4). This varied significantly by hospital, ranging from 0·0% (doing no

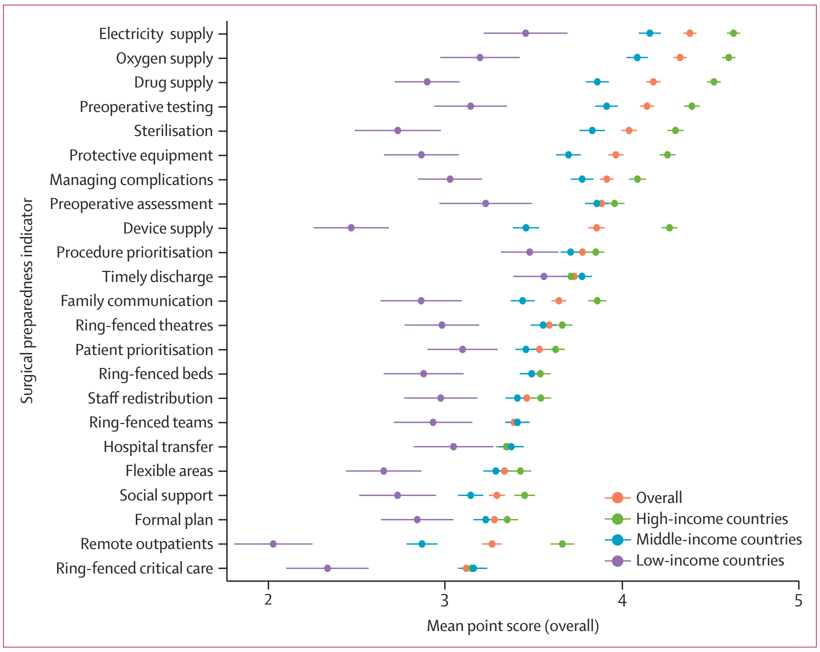

Figure 4: **Mean ratings of hospitals across surgical preparedness indicators**
Scores are a mean following ratings from 1632 participants. Indicators are ordered from highest to lowest mean score (out of 5) overall by indicator.

planned surgery) to 200·0% (doing twice as many planned surgeries than the pre-pandemic baseline). A histogram of SVR across World Bank income groups is reported in the appendix (p 14). The proposed causal model is reported in the appendix (p 16), and figure 5 shows the SPI score against the SVR, overall and across key subgroups. A linear association was observed between SPI score and SVR with a ten-point total SPI score increase associated with a 3·6% (95% CI 3·0 to 4·1; p<0·0001) increase in SVR in the mixed-effects model. Hospitals in MICs (–8·37% [95% CI –8·45 to –8·29]; p<0·0001) and LICs (–10·56% [–14·89 to –6·2]; p<0·0001) versus HICs were associated with a reduced SVR. Private (3·01% [0·12 to 5·91]; p<0·0001) and mixed public and private (3·20% [1·02 to 5·37]; p=0·0002) hospitals were both associated with increased SVR versus public hospitals. No significant associations between hospital location (urban *vs* rural or mixed) and SVR were observed (appendix p 10). On subgroup analysis, association between SPI score and SVR was observed in HICs (4·8% [4·1 to 5·5]; p<0·0001), MICs (2·8% [2·0 to 3·7]; p<0·0001), and LICs (3·8 [1·3 to 6·7]; p<0·0001); moderate (3·5 [2·7 to 4·2%]; p<0·0001) and high (4·1 [3·3 to 4·8]; p<0·0001) COVID-19 burden areas; public (3·6% [3·0 to 4·2]; p<0·0001) and private hospitals (4·1% [3·1 to 5·2]; p<0·0001); and in urban (4·2% [3·3 to 5·1]; p<0·0001), rural (4·9 [1·6 to 8·2]; p=0·0046), and mixed locations (3·4 [2·7 to 4·1]; p<0·0001).

Discussion

We have developed, measured, and validated a hospital-level SPI to support strengthening of elective surgery systems against external shocks. The SPI showed variability at subnational and hospital levels, identifying areas that can improve to create resilience in local surgical systems. Using COVID-19 as an example, a 10-point increase in the SPI was associated with a 3·6% increase in the planned surgical volume ratio. This relationship was robust across income settings, hospital types, and COVID-19 burdens. Hospitals with private versus public financing and in HICs were able to maintain a higher SVR than those in MICs or LICs, indicating the importance of hospital resourcing as a mediator of planned surgical throughput. Our findings suggest that the under-resourced surgical systems, identified as at risk by the *Lancet* Commission on global surgery,[23] will also be at greatest risk of secondary effects and delayed recovery from COVID-19. Routine SPI assessment might help to identify actionable targets for local policy, advocacy, and investment in surgery and anaesthesia service strengthening that complement existing frameworks for global health security.[24,25] Focused efforts to address surgical preparedness will be essential in addressing growing backlogs and mitigating against harm for patients awaiting surgery.

The 23 surgical preparedness indicators are easy to measure without additional resources, with moderate ICC values, and they allow local hospital teams to identify targets that are relevant to them and are actionable. There was significant variability in performance across indicators and across resource settings. For example, ring-fenced critical care beds was rated as being challenging in HIC, MIC, and LIC settings, suggesting a challenge that might be hard to surmount. Conversely, device supply, drug supply, and remote outpatients appointments were scored lower in lower-income settings, perhaps highlighting important areas for advocacy and service investment. Public hospitals and those in rural settings had lower SPI scores, highlighting vulnerable hospital types that warrant future focus.[26] The finding that better resourced surgical services were more resilient to system stress during SARS-CoV-2, with a more rapid recovery, aligns with other research in this area.[27] Country-level analysis showed consistency of the SPI with other measures of health system resilience, such as the Global Health Security index, and strong correlation with UHC service coverage and other measures of wealth equality and development. However, the SPI has strong clinical use beyond these population-level measures by allowing hospital benchmarking and highlighting areas for targeted action.

Other indices exist to address both health system preparedness and surgical capacity separately, but they do not combine the immediate need to focus on surgery at a subnational or hospital level and preparedness for external shocks.[28,29] In a review of whole-health system preparedness indicators, no index was meaningfully associated with clinical outcomes, and no surgery-specific indices were found.[11] Other frameworks exist to evaluate surgical capacity in isolation (the PIPES checklist,[12] WHO Situational Assessment tool,[13] and Ethiopian Hospital Assessment tool[30]). However, these are not designed to dynamically assess preparedness (ie, the response of services to external system pressure). They are also complex, long, and not feasible for regular application.

Our index was validated in the context of the SARS-CoV-2 pandemic, but it is likely to be generalisable beyond this setting. In a consensus exercise, independent international raters considered the indicators all to have high or moderate relevance across five example scenarios. However, the index might not have full content validity across every external shock recorded. For example, in the case of seasonal pressures (heatwaves or winter pressures) adequate temperature control in clinical areas through air conditioning or heating might be considered an important additional indicator. In addition, the relative importance of SPI indicators might change from system stressor to stressor and from country to country; for example, during the COVID-19 recovery period, staff shortages might be the primary limiting factor for delivery of planned surgery. This has been compounded over time due to burnout and staff sickness. Therefore, we consider the SPI to be a minimum core indicator set to underpin elective surgical system preparedness with relevance across a variety of scenarios. However, the SPI requires validation and a potential need for adaptation for other external stressors exists, highlighting an important area for ongoing research.

Surgery has been neglected from planning for pandemic recovery, despite being a core component of functioning health-care systems.[23,31] The SPI presents a consensus response by the international community to tackle the issue of neglect of surgery from planning. However, our study has limitations. First, this cross-sectional assessment of preparedness does not account for hospitals at different stages of the readiness–response–recovery cycle.[32] Second, the index does not inform the net benefit of restoring surgery versus other hospital activities; however, surgical service preparedness is an essential component of holistic health system resilience: it strengthens other health-care processes (eg, readiness to provide oxygen)[33] and transparent prioritisation will be key in competition for restricted resources.[34] Third, 868 (53%) of the 1632 hospitals had only one assessor. Differences in preparedness might exist between specialties or operating theatres that are not reflected here, and we were unable to assess variability between subgroups of assessors in more details. Fourth, there was some imbalance in representation between HICs, MICs, and LICs in both indicator development and the cross-sectional assessment. However, data were collected from a large sample of 744 (46·6%) hospitals in MICs and LICs indicating generalisability. Fifth, data suggest that some hospitals in countries with lower COVID-19 burden at the time of assessment (eg, Australia and China) had a lower SPI score, but still were able to maintain their planned surgical volume. To address confounding due to COVID-19 pressures, we adjusted for this in modelling and did a subgroup analysis in high and moderate COVID-19 burden areas; no countries were classified as low COVID-19 burden. Sixth, barriers and facilitators to implementation of the SPI framework are not yet fully understood; we include an online assessment tool to support future implementation and evaluation. Seventh, our surrogate measure of COVID-19 burden (OxCGRT) did not account for government mandates to pause planned surgical care, which might have led to unmeasured

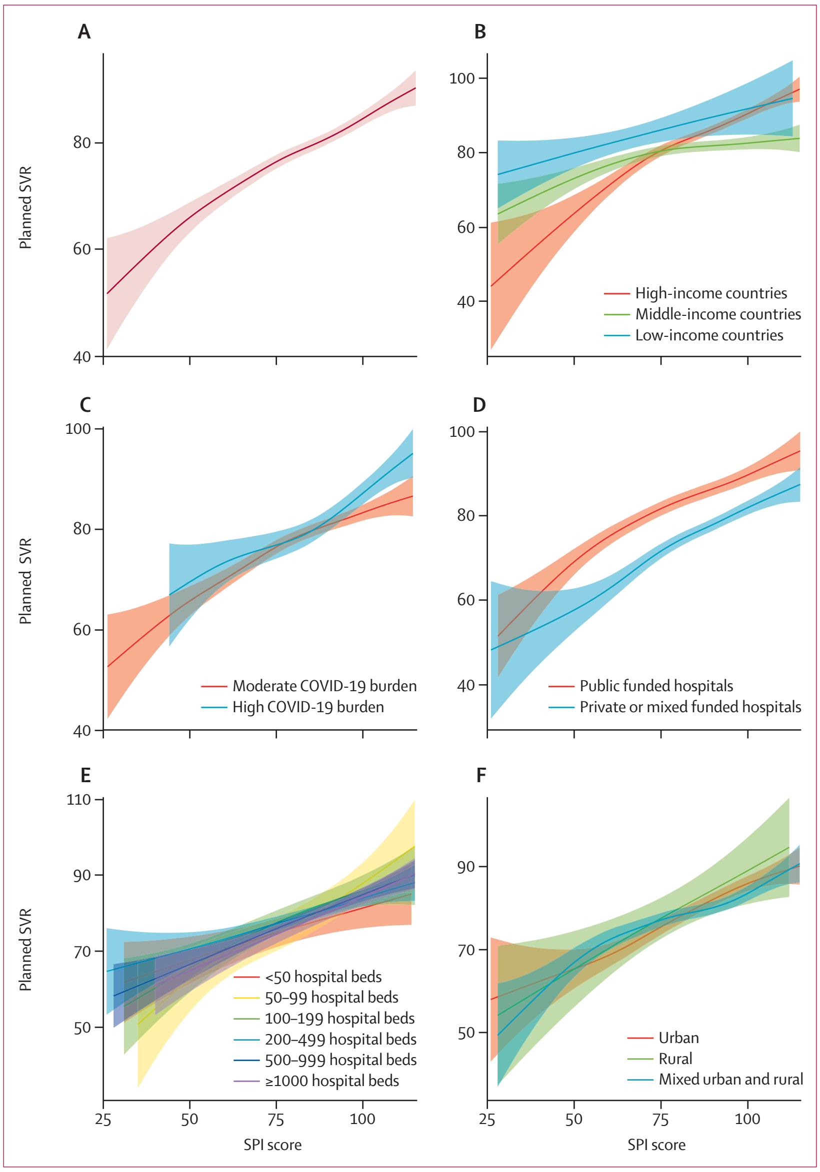

***Figure 5*: Association between SPI scores and hospitals' planned surgical volume ratio**
Association between SPI scores and hospitals' planned surgical volume ratio overall (A) and by country income status (B), COVID-19 burden (C), hospital funding mechanism (D), number of hospital beds (E), and hospital location (F). The planned surgical volume ratio was calculated as the ratio of each hospital's observed planned surgical volume over a 1-month assessment period against the expected planned surgical volume based on data from the same month in 2019 (the prepandemic baseline) and expressed as a percentage. Shaded areas are 95% CIs. SPI=surgical preparedness index. SVR=surgical volume ratio.

For more on **COVID-19 burdens at the time of our assessment** see https://ourworldindata.org/coronavirus

confounding. Eighth, we included several plausible confounders in mixed-effects modelling supported by causal relationships presented in a directed acyclic graph. However, there might be residual unmeasured confounding or measurement error that has been unaccounted for. Ninth, our primary outcome measure was data driven and pragmatic, but represented a single cross-sectional assessment, calculated as a relative measure of surgical volume. This should be considered when applying the index to national health policy in which absolute measures of outcomes and effects might be important. Tenth, interpretation of composite measures, such as the SPI, is challenging, and we have only explored the relationship between the total index score and SVR. We are unable to judge the relative importance of individual indicators, which might vary across specialties, hospitals, and resource contexts. Future exploration of the scaling and measurement properties of the index and differential functioning of the indicators is required during future development. Future iterations of the SPI could consider normalising or transforming the scale to make its minimum and maximum values more intuitive (eg, 0–100), but this should be balanced with clinical use and interpretability of the output for local assessors. Eleventh, unplanned surgery is an important component of surgical systems, especially in LMICs in which a larger proportion of patients present to care services requiring emergency or immediate care.[35] The SPI has been developed and validated in planned surgery only and is not designed to be applied in emergency systems. Finally, we have not considered the safety and efficacy of the surgeries. There are likely to be differences across resource settings that might be exacerbated by the whole-health system effect of COVID-19 and should be considered in future work.[3,35]

As the recovery following the COVID-19 pandemic continues to gather pace there is a need for urgent and regular (eg, annual) hospital self-assessment using the SPI. When possible, this assessment should be integrated with existing quality and safety programmes and national surgical, obstetric, and anaesthesia planning. SPI implementation alongside national surgical, obstetric, and anaesthesia planning will add resilience to national capacity building that is aleady under way. Improving preparedness is likely to strengthen planned surgical services against future external shocks and support upscaling of surgery to address growing demands. Therefore, the SPI supports a major priority area for WHO for ongoing progress towards Sustainable Development Goal 3: Health and Wellbeing.[36–38] COVID-19 is just one form of external shock that puts additional pressure on planned surgical care pathways. Other epidemics, such as influenzas and Ebola virus, have had significant effects on surgical services over the past decade.[39] Natural phenomena associated with climate change, stresses from geopolitical instability, and conflict have also already had a substantial effect and continue to pose a substantial future threat to surgical system functioning. Surgical preparedness is a core part of the response to these stressors in minimising suffering and loss of life.[40,41] Although the SPI has been developed during the COVID-19 pandemic, it has been specifically designed to be applicable to any context of health system pressure. Other context-specific modifications (eg, to incorporate sustainable measures for climate resilience) might become necessary as use of the index expands into global surgical practice.[42] Best processes for implementation of the SPI for longitudinal assessment of a hospital's preparedness is an urgent research area for ongoing development.

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Contributors

The writing group and the statistical analysis group (JCG, KAM, OO, BK, EH, AAB) contributed to writing, data interpretation, and critical revision of the manuscript. The writing group, operations committee, 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. All members of the writing group had full access to the data in the study. JCG, KAM, OO, BK, EH, and AAB verified the underlying data in the study. JCG, AAB, and the writing committee had final responsibility for the decision to submit for publication. Detailed role descriptions of all contributing collaborating authors are shown in the appendix (pp 28–54).

Declaration of interests

RP has received research grants or consultancy fees or both from Edwards Lifesciences, Intersurgical, and GlaxoSmithKline. JM has consulted for WHO on projects related to perioperative preparedness. TA has received consultancy fees from MSD unrelated to this work. All other members of the writing group declare no competing interests.

Data sharing

Anonymised data are available upon request from the writing group, and successful completion of a data sharing agreement through an Application Programming Interface linked to the REDCap data server hosted at Birmingham Clinical Trials Unit, University of Birmingham, Birmingham, UK. Summary data and a self-assessment tool are available online.

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Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

Supplement to: NIHR Global Health Unit on Global Surgery, COVIDSurg Collaborative. Elective surgery system strengthening: development, measurement, and validation of the surgical preparedness index across 1632 hospitals in 119 countries. *Lancet* 2022; published online Oct 31. https://doi.org/10.1016/S0140-6736(22)01846-3.

Supplementary table 1. Description of Surgical Preparedness Indicators to support hospital assesssment

Surgical Preparedness Indicators	Description
Facilities and consumables	
1. Availability of ring-fenced (reserved) planned surgery theatres	The ability of a hospital to ring-fence (i.e., reserve) theatres to use only for the planned operations during a period of external stress. This improves preparedness by ensuring that sufficient theatre space is available for planned surgery even if there is an increase in emergency surgery volume (e.g., falls risk during winter pressures, complications of endemic and pandemic diseases, high volume trauma).
2. Availability of ring-fenced (reserved) planned surgery beds	The ability of a hospital to ring-fence (i.e., reserve) ward beds to be occupied only by patients before and/or after planned surgery during a period of external stress. This improves preparedness by ensuring that beds are available for preoperative optimisation and/or postoperative care of patients undergoing planned surgery when there is a higher than anticipated volume of hospital admissions (e.g., during an airborne or non-airborne pandemic, natural disaster, or extreme weather event).
3. Availability of ring-fenced (reserved) critical care beds for planned surgery	The ability of a hospital to ring-fence (i.e., reserve) critical care beds to be occupied only by patients after planned surgery during a period of external stress. This improves preparedness by ensuring sufficient capacity for admission of patients that were at high baseline risk of surgical complications due to comorbid disease or operative severity, that have an intraoperative complication, or that deteriorate after surgery on a ward-based environment. Critical care services are put under pressures during a most external stressor scenarios, providing organ support and high-intensity care.
4. Flexibility to re-arrange hospital areas to provide a segregated pathway (separate areas) for planned surgery	The ability of a hospital to re-arrange clinical areas to provide separate areas of the hospital for delivery of pre-, intra- and post-operative care to planned surgical patients. This has two mechanisms of improving preparedness: (1) firstly, in concentrating expert perioperative staff and resources in areas where planned surgical patients are receiving care to improve efficiency and safety; (2) secondly, to reduce risk of nosocomial transmission of endemic and pandemic diseases from infected patients undergoing care in nearby areas (e.g., malaria, influenza, COVID-19, Ebola). Whilst perhaps most relevant to airborne and non-airborne pandemics, their risk increases during natural disasters, warfare and extreme weather events and can compound reduction in planned surgical volume.
5. Access to diagnostics and interventions to identify and treat surgical complications	A hospital's capacity to provide: • Urgent diagnostic tests including (and not limited to) haematology, biochemistry, microbiology, plain radiographs, endoscopy, computer tomography (CT) and magnetic resonance (MR) imaging. • Urgent postoperative interventions including (and not limited to) transfusion of blood and blood products, antimicrobial therapy, nutrition, reoperation, interventional radiology, and critical care services. This improves preparedness by improving capacity to rescue, reducing severity of complications, in-hospital bed days and mortality for patients undergoing planned surgery.
6. Reliable supply of electricity	The reliability of a hospital's electricity supply when providing pre-, intra- and post-operative care to planned surgical patients. This can improve preparedness by ensuring care can be safely delivered when demand for electricity rises (i.e., increased number of hospital admissions and critical care) or supply falls (e.g., during political stability, natural disasters and extreme weather events).
7. Reliable supply of supplementary oxygen	The reliability of a hospital's supply of supplemental oxygen available to deliver care to planned surgical patients. Supply and demand are likely to fluctuate during many external stress scenarios including for airborne pandemics such as COVID-19 or influenza, non-airborne pandemics for patients presenting with sepsis, high volume trauma, and lower respiratory tract infection during extreme weather events.
8. Reliable supply and management of essential perioperative drugs	The reliability of a hospital's supply of essential perioperative medications available to deliver care to planned surgical patients. These may relate to different aspects of pre-, intra-, and post-operative care, and are likely to fluctuate between operation types, from patient to patient and across different surgical specialties. This improves preparedness by ensuring key drugs for induction and maintenance of anaesthesia, perioperative pain relief, multi-relaxation, and other essential aspects of perioperative care can be delivered in line with local practice. Again, demand and supply may fluctuate across a wide range of external stressors.

9. Reliable supply and management of devices and implants	The reliability of a hospital's supply of devices and implants for planned surgical patients. The necessity, type and volume of devices and implants is likely to vary substantially by specialty and by local training and standards of practice. For some operations, a procedure will not be able to be performed without an essential device of implant, whilst for others an implant or device may improve the quality or completeness of the operation, but another approach is feasible. Surgical systems with a reliable supply of devices and implants will be less likely to have cancellations in the event of fluctuating supply and demand across a wide range of external stressors.
10. Sufficient surgical instrument and local sterilisation processes	The ability of a hospital to maintain sufficient supplies of surgical instruments required for the local case-mix of planned surgery; the volume and types of surgical instruments required are likely to vary significantly from hospital to hospital and specialty to specialty. This includes the availability and resilience of sterilisation processes for reusable instruments and devices. This improves preparedness by preventing cancellations or unsafe surgery due to the unavailability of critical equipment to complete a planned procedure.
11. Availability of protective measures for theatre teams	Availability of protective measures for theatre teams, including surgical, anaesthesia and operating theatre nurse and support staff. This includes any measures required for teams to perform planned surgery safely and may vary across different external system stressors. These could include: • Personal protective equipment to prevent spread of bloodborne, droplet and airborne pathogens associated with occupational risk such as surgical gowns, hats, face masks, shoes, and theatre scrubs • Appropriate services for testing (and vaccination where possible) for diseases with occupation risks such as Hepatitis B and C, HIV, and pandemic or endemic diseases such as COVID-19, influenza, or malaria. • Security measures to protect staff from threat of physical or psychological harm (e.g., during periods of political or social unrest) • Structural measures in the theatre itself to protect staff from harm in the event of a natural disaster or extreme weather event. Surgery and anaesthesia cannot be delivered without adequate, trained staffing and these measures improve preparedness by reducing staff sickness, injury and improving retention.
Staffing	
12. Ability to redistribute staff (within and between hospitals) to maintain planned surgical capacity	The ability of a hospital to redistribute staff within and between hospitals to maintain planned surgery and anaesthesia services. Redistribution of staff can be required to cover staff absence or redeploy workforce across multiple perioperative care areas such as admission areas, theatres, critical care, and surgical wards. Higher absenteeism rates would be anticipated during most periods of external system stress, due to higher levels of physical sickness (e.g., airborne, non-airborne pandemics, extreme weather) and psychological stress (e.g., warfare, natural disasters).
13. Ring-fenced (reserved) teams to provide planned surgical care	The ability of a hospital to ring-fence (i.e., reserve) teams along the perioperative pathway to support delivery of planned operations during a period of external stress. This improves preparedness by ensuring that sufficient staffing is available even where there are increased demands on other hospital services which may otherwise require redeployment or retraining of surgical staff (e.g., pandemic diseases, natural disasters, extreme weather) or higher than anticipated volumes of emergency surgery (e.g., falls during cold weather extremes, high volume trauma during periods of political instability).
Prioritisation	
14. Cross-specialty patient prioritisation for surgery	The ability of a hospital to prioritise patients for planned surgical procedures across multiple specialties using locally, regionally, or nationally defined criteria. These could be based for example on individual patient risk, condition-specific risks of delay, or effectiveness (or cost-effectiveness) of surgical intervention. During periods of external pressure, a robust prioritisation system that works across surgical providers in the hospital will ensure that surgical pathways are used effectively and for patients that will benefit most and/or be least likely to have their surgery cancelled during periods of external stress. This may change dynamically over time and from theatre to theatre or hospital to hospital.
15. Ability to identify and cancel procedures of limited clinical value (non-essential surgery)	Ability of hospitals to identify patients who have been booked for procedures of limited clinical value and cancel or delay these to provide planned surgical capacity for patients that will benefit most and/or be least likely to have their surgery cancelled during periods of external stress. This value judgment can be locally, regionally, or nationally defined and based on criteria related to individual patients' risk and likely effectiveness of surgical intervention. This will improve preparedness

	by stabilising demand on planned surgical services during periods of external pressure and protecting services and staffing for patients that need them most.
Systems	
16. Formal operational plan to continue planned surgery during periods of external system stress	The availability of a formal plan to continue planned surgery during periods of system stress and ability of the hospital to operationalise this to protect planned surgical capacity. This improves preparedness by galvanising a whole-service approach to facilities, staffing, prioritisation and systems before a high-stress external event occurs. Plans should be individualised to the external stressor scenario (e.g., airborne pandemic, warfare, extreme heat) as scenario-specific factors and mediators should be considers. In the absence of experiencing the specific external stressor in question, the frequency, quality, and level engagement of simulated scenarios could be used as a surrogate measure of the ability of a hospital to operationalise this plan.
17. Ability to conduct preoperative assessment in the community	Ability of a surgery and anaesthesia service to conduct pre-operative assessment in the community. This could include blood tests, electrocardiography, lung function tests or any other measure for preoperative risk stratification in the community. This improves preparedness by reducing pressure on hospital inpatient and outpatient services during periods with higher level of hospital assessments and admissions which could otherwise be prioritised at the expense of preoperative assessments before planned surgery.
18. Access to preoperative testing for endemic and epidemic diseases	Ability of a surgery and anaesthesia service to provide preoperative testing for endemic and epidemic diseases for patients at risk. This could include endemic (e.g., malaria, dengue fever), epidemic and pandemic diseases (e.g., influenza, COVID-19). This improves preparedness by reducing likelihood of surgical cancellations and/or nosocomial transmission to staff members or other patients awaiting planned surgery.
19. Ability to transfer patients to another hospital with greater capacity	Abilty of a hospital network to transfer of care of a patient awaiting planned surgery away from their booking hospital to another hospital with greater capacity. This improves preparedness by temporarilty redirecting selected patients to centres with different services, that are facing less severe external pressures or to support continuation of planned surgery for another group where different specialties are disproportionately affected by a crisis.
20. Ability to facilitate timely discharges	Ability of a hospitals to identify patients that are medically fit for discharge and facilitate their discharge back into the community. This improves preparedness by reducing pressure on hospital beds and staffing to free space for patients awaiting planned surgery. It is likely to require multidisciplinary involvement which may be different between different patients, hospitals, and settings.
21. Social support system to facilitate safe discharge	Capacity of a surgery and anaesthesia service to provide social support in the community to patients after discharge. This supports holistic care for patients at the point of discharge and prevents blocks to in their return to community care. This indicator encompasses a system-level approach to *Indicator 20. Ability of hospitals to facilitate timely discharges.*
22. Capacity to use telephone or video calls for outpatient appointments	A hospital's capacity to provide remote monitoring services such as telephone or video calls for outpatient assessment or consultation before and after surgery. This improves preparedness by reducing pressure on hospital outpatient services during periods with high system pressure where areas or staff could be redeployed to other clinical areas. It also allows outpatient services to continue where there are safety concerns with hospital visitation (e.g., during airborne or non-airborne pandemics, natural disasters or extreme weather conditions).
23. Capacity and capability to communicate with family members	Capacity (i.e., time and staff availability) and capability (i.e., technical infrastructure, private space) to communicate (remotely or in-person) with family members to provide update on care of patients undergoing planned surgery. This improveness preparedness by supporting holistic and patient-centred care even during periods with safety (e.g., pandemics, political instability), logistical (e.g., long travel distances or cost during economic recession) or comfort (e.g., extreme weather) concerns for family members.

Supplementary table 2. Summary of international consultation (Delphi consensus Round 1 and 3 voting)

		Round 1 voting			Round 3 voting			
Short-hand indicator	**Indicator text (Round 1 voting)**	**Importance**	**Easy to measure**	**Round 1 Outcome$**	**Essential**	**Desirable**	**Remove**	**Round 3 Outcome**
Ring-fenced theatres	Availability of ring-fenced (reserved) elective surgery theatres	83.33	79.32	Accepted after Round 1	-	-	-	Include
Ring-fenced beds	Availability of ring-fenced (reserved) elective surgery beds	80.82	73.97	Accepted after Round 1	-	-	-	Include
Ring-fenced critical care	Availability of ring-fenced (reserved) critical care beds for elective surgery	78.89	73.21	Accepted after Round 1	-	-	-	Include
Flexible areas	Flexibility to rearrange hospital areas to provide a segregated pathway for elective patients	79.79	79.79	Accepted after Round 1	-	-	-	Include
Managing complications	Access to diagnostics and interventions to identify and treat surgical complications	85.45	70.88	Accepted after Round 1	-	-	-	Include
Electricity supply	Reliable supply of electricity	92.47	83.61	Accepted after Round 1	-	-	-	Include
Oxygen supply	Reliable supply of supplementary oxygen	94.50	81.71	Accepted after Round 1	-	-	-	Include
Drug supply	Reliable supply and management of essential perioperative drugs	92.48	76.27	Accepted after Round 1	-	-	-	Include
Device supply	Reliable supply and management of devices and implants	82.21	72.70	Accepted after Round 1	-	-	-	Include
Sterilisation	Sufficient surgical instrument and local sterilisation processes	92.76	75.64	Accepted after Round 1	-	-	-	Include
Protective equipment	Availability of personal protective equipment for theatre teams (including testing & vaccination)	89.39	71.98	Accepted after Round 1	-	-	-	Include
Staff redistribution	Ability to redistribute staff (within and between hospitals) to maintain capacity	79.89	60.09	Progress to Round 3 voting	67.6%	25.0%	7.4%	Include
Ring-fenced teams	Ring-fenced (reserved) teams to provide elective surgical care	77.03	64.98	Progress to Round 3 voting	55.9%	36.8%	7.4%	Include
Staff wellbeing	Access to counselling and supportive services for staff wellbeing	69.41	57.00	Progress to Round 3 voting	41.2%	45.6%	13.2%	Exclude
Staff absence	Ability to cover staff absence	87.21	66.64	Progress to Round 3 voting	70.6%	23.5%	5.9%	Include
Digital referrals	Use of paperless systems for new patient referrals	64.97	68.61	Progress to Round 3 voting	25.0%	57.4%	17.6%	Exclude
Remote outpatients	Capacity to use telephone or video calls for outpatients appointments	77.05	73.35	Accepted after Round 1	-	-	-	Include
Patient prioritisation	Cross-specialty surgical patient prioritisation system	78.86	60.24	Progress to Round 3 voting	50.0%	44.1%	5.9%	Include
Procedure prioritisation	Ability to identify and cancel procedures of limited clinical value	82.24	60.83	Progress to Round 3 voting	70.6%	27.9%	1.5%	Include
Digital planning	Access to a digital theatre planning system that optimises theatre usage	67.65	66.42	Progress to Round 3 voting	23.5%	64.7%	11.8%	Exclude
Formal plan	Formal plan to continue elective surgery during periods of increased pressure	87.30	74.36	Accepted after Round 1	-	-	-	Include
Digital assessment	Capacity for digital (virtual) preoperative assessment	68.83	68.83	Progress to Round 3 voting	25.0%	63.2%	11.8%	Exclude
Preoperative assessment	Ability to conduct preoperative testing (e.g. blood tests, ECG) away from an acute site hospital	75.80	72.38	Accepted after Round 1	-	-	-	Include
Preoperative testing	Access to routine preoperative testing for endemic/epidemic diseases (e.g., malaria, influenza, COVID-19)	90.42	81.92	Accepted after Round 1	-	-	-	Include
Hospital transfer	Access to a hospital network to transfer care of elective surgery patients to a linked hospital with greater capacity	78.00	65.32	Progress to Round 3 voting	58.8%	38.2%	2.9%	Include
Timely discharge	Access to procedures and technologies to facilitate timely discharges	78.08	60.94	Progress to Round 3 voting	42.6%	50.0%	7.4%	Discussion
Social support	Social support system to facilitate safe discharge	81.21	61.92	Progress to Round 3 voting	41.2%	49.2%	9.6%	Discussion
Family communication	Capacity to communicate with family members during periods of restricted hospital visiting	79.65	68.00	Progress to Round 3 voting	47.1%	47.1%	5.9%	Discussion
Post-discharge care	Capacity to provide post-discharge care in the community (e.g. health workers)	77.29	58.55	Progress to Round 3 voting	47.1%	38.2%	14.7%	Exclude
Policy communication	Capacity to communicate with decision makers to adapt surgical services	83.05	48.77	Progress to Round 3 voting	51.5%	36.8%	11.8%	Exclude
Colleague communication	Availability of a communication pathway that reaches all the professionals involved in surgical care	80.09	54.79	Progress to Round 3 voting	48.5%	35.3%	16.2%	Exclude
Financing	Clear financing mechanism to support elective surgery	78.39	51.52	Progress to Round 3 voting	48.5%	33.8%	17.6%	Exclude

Round 2 (iterative development and discussion) did not include voting by the development group so is omitted here.

Supplementary table 3. Summary of international consultation (Delphi consensus Round 4 discussion)

Shorthand	Round 3 virtual survey results	Round 4 focus group discussion	Final agreed indicators
Ring-fenced theatres	Availability of ring-fenced (reserved) elective surgery theatres	Identified need to explain definition of ring-fenced in subtext.	1. Availability of ring-fenced (reserved) planned surgery theatres
Ring-fenced beds	Availability of ring-fenced (reserved) elective surgery beds	Identified need to explain definition of ring-fenced in subtext.	2. Availability of ring-fenced (reserved) planned surgery beds
Ring-fenced critical care	Availability of ring-fenced (reserved) critical care beds for elective surgery	Identified need to explain definition of ring-fenced in subtext.	3. Availability of ring-fenced (reserved) critical care beds for planned surgery
Flexible areas	Flexibility to rearrange hospital areas to provide a segregated pathway for elective patients	Agreed with wording, considered to improve clarity of pathway to ensure clear that separate areas should be provided.	4. Flexibility to re-arrange hospital areas to provide a segregated pathway (separate areas) for planned surgery
Managing complications	Access to diagnostics and interventions to identify and treat surgical complications	Considered including ring-fenced to indicator description. Overall feeling that would be applied flexibly without a requirement to be ring-fenced.	5. Access to diagnostics and interventions to identify and treat surgical complications
Electricity supply	Reliable supply of electricity	Agreed with wording	6. Reliable supply of electricity
Oxygen supply	Reliable supply of supplementary oxygen	Agreed with wording	7. Reliable supply of supplementary oxygen
Drug supply	Reliable supply and management of essential perioperative drugs	Agreed with wording	8. Reliable supply and management of essential perioperative drugs
Device supply	Reliable supply and management of devices and implants	Agreed with wording	9. Reliable supply and management of devices and implants
Sterilisation	Sufficient surgical instrument and local sterilisation processes	Discussion as to whether to split out into safe surgical instruments + sterilisation. In overall context of index, decision to move forwards with current wording	10. Sufficient surgical instrument and local sterilisation processes
Protective equipment	Availability of personal protective equipment for theatre teams (including testing & vaccination)	Discussion that testing, vaccination and PPE are too COVID-specific for a generic index so decision to examples in main indicator text.	11. Availability of protective measures for theatre teams
Staff redistribution	Ability to redistribute staff (within and between hospitals) to maintain capacity	Crossover with "Ability to cover staff absence" so decision to combine. Added planned surgical capacity to ensure consistent and clear across indicators.	12. Ability to redistribute staff (within and between hospitals) to maintain planned surgical capacity
Ring-fenced teams	Ring-fenced (reserved) teams to provide elective surgical care	Identified need to explain definition of ring-fenced in subtext. Felt important to keep reserved as globally relevant terminology. Considered large crossover with staff abscence	13. Ring-fenced (reserved) teams to provide planned surgical care
Staff absence	Ability to cover staff absence	Combined with "Ability to redistribute staff (within and between hospitals) to maintain capacity"	-
Patient prioritisation	Cross-specialty surgical patient prioritisation system	Agreed with wording	14. Cross-specialty patient prioritisation for surgery
Procedure prioritisation	Ability to identify and cancel procedures of limited clinical value	Agreed to improve description with 'non-essential surgery'	15. Ability to identify and cancel procedures of limited clinical value (non-essential surgery)
Formal plan	Formal plan to continue elective surgery during periods of increased pressure	Add 'operational' to plan to ensure this is actionable. Add 'external system stress' to definition to describe high pressure perioúds	16. Formal operational plan to continue planned surgery during periods of external system stress
Preoperative assessment	Ability to conduct preoperative testing (e.g. blood tests, ECG) away from an acute site hospital	In the community added to improve interpretability	17. Ability to conduct preoperative assessment in the community
Preoperative testing	Access to routine preoperative testing for endemic/epidemic diseases (e.g. malaria, COVID-19, influenza)	Discussion to drop examples in generic index and improve description in supporting materials	18. Access to preoperative testing for endemic and epidemic diseases
Hospital transfer	Access to a hospital network to transfer care of patients requiring elective surgery to a linked hospital with greater capacity	Simplified language	19. Ability to transfer patients to another hospital with greater capacity
Timely discharge	Access to procedures and technologies to facilitate timely discharges	Simplified language to improve relevance across settings. Group agreed that flow through the hospital an essential component of prepared health systems.	20. Ability to facilitate timely discharges
Social support	Social support system to facilitate safe discharge	Group agreed that social support systems, whilst not universally available, improve surgical system preparedness. Discussed crossover with 'timely discharge' but group considered them to be separate entities.	21. Social support system to facilitate safe discharge
Remote outpatients	Capacity to use telephone or video calls for outpatients appointments	Agreed with wording.	22. Capacity to use telephone or video calls for outpatient appointments
Family communication	Capacity to communicate with family members during periods of restricted hospital visiting	Group felt important to include & universal. Suggested wording capability rather than capacity (i.e. infrastructure rather than human resource issues)	23. Capacity and capability to communicate with family members

Supplementary table 4. Features of hospitals included in Surgical Preparedness Index (SPI) measurement

Factor	Levels	World Bank income group			
		High	Middle	Low	Total
		N=887	N=675	N=70	N=1632
Hospital features					
Funding	Public (government)	718 (80.9)	445 (65.9)	54 (77.1)	1217 (74.6)
	Private	51 (5.7)	138 (20.4)	7 (10.0)	196 (12.0)
	Mixed public and private	118 (13.3)	92 (13.6)	9 (12.9)	219 (13.4)
Urgency	Planned only	28 (3.2)	32 (4.7)	2 (2.9)	62 (3.8)
	Planned and unplanned	859 (96.8)	643 (95.3)	68 (97.1)	1570 (96.2)
Setting	Urban	376 (42.4)	241 (35.7)	17 (24.3)	634 (38.8)
	Rural	22 (2.5)	22 (3.3)	10 (14.3)	54 (3.3)
	Mixed urban and rural	489 (55.1)	412 (61.0)	43 (61.4)	944 (57.8)
Hospital Beds	Less than 50	21 (2.4)	50 (7.4)	11 (15.7)	82 (5.0)
	50-99	38 (4.3)	58 (8.6)	8 (11.4)	104 (6.4)
	100-199	73 (8.2)	105 (15.6)	11 (15.7)	189 (11.6)
	200-499	286 (32.2)	197 (29.2)	21 (30.0)	504 (30.9)
	500-999	314 (35.4)	146 (21.6)	16 (22.9)	476 (29.2)
	1000+	155 (17.5)	119 (17.6)	3 (4.3)	277 (17.0)
Country features					
Oxford COVID-19 government response index	Mean (s.d.)	63.1 (8.2)	59.4 (11.0)	40.3 (16.0)	60.6 (10.9)
COVID-19 burden	Moderate	323 (36.4)	316 (46.8)	56 (80.0)	695 (42.6)
	High	563 (63.5)	349 (51.7)	14 (20.0)	926 (56.7)
	Missing	1	10	0	11

$Oxford COVID-19 government response index contains 17 indicators around four themes of closure and containment, health and economic support with a normalised range between 0 (no government response) and 100 (most stringent government response). Each hospital was given a classification based on the country's status at the time of assessment: low COVID-19 burden (index <20), moderate COVID-19 burden (20-60), and high COVID-19 burden (>60).

Supplementary table 5. Surgery Preparedness Index scores by country

Country*	Assessments (N=4714)	Hospitals (N=1632)	Min	Max	Mean	s.d.
Afghanistan	4	1	46	100	77.0	22.5
Albania	4	3	80	92	88.0	5.7
Algeria	9	7	48	72	61.7	8.6
Argentina	49	15	57	115	93.7	13.0
Aruba	1	1	80	80	80.0	NA
Australia	96	47	64	114	90.7	10.7
Austria	44	15	76	109	94.4	9.2
Azerbaijan	4	3	68	81	75.0	5.5
Bahamas (the)	1	1	66	66	66.0	NA
Bahrain	8	4	66	114	92.6	14.9
Bangladesh	13	5	67	103	87.2	12.5
Barbados	8	1	49	74	64.3	7.8
Belarus	2	2	58	83	70.5	17.7
Belgium	14	9	69	109	91.4	10.6
Benin	3	2	76	76	76.0	0.0
Bolivia (Plurinational State of)	1	1	111	111	111.0	NA
Bosnia and Herzegovina	12	2	71	102	86.4	8.3
Botswana	3	1	72	81	77.3	4.7
Brazil	82	38	48	115	85.7	15.7
Bulgaria	17	8	63	110	88.5	15.4
Cambodia	1	1	63	63	63.0	NA
Cameroon	3	1	68	93	81.0	12.5
Canada	52	22	60	115	90.2	13.5
Chile	13	6	63	102	87.5	9.9
China	4	3	80	93	86.8	6.7
Colombia	44	14	63	109	87.2	12.7
Croatia	18	9	69	112	87.3	14.4
Cyprus	4	3	60	69	64.5	4.2
Czechia	3	3	80	96	90.7	9.2
Denmark	3	3	102	106	103.7	2.1
Dominican Republic (the)	5	3	100	114	108.4	5.8
Ecuador	8	5	82	110	92.5	8.8
Egypt	187	56	46	115	81.2	13.1
Estonia	1	1	91	91	91.0	NA
Ethiopia	37	16	43	102	63.2	14.7
Finland	5	4	81	90	84.8	4.4
France	65	35	50	114	85.9	14.6
Georgia	1	1	68	68	68.0	NA
Germany	99	37	69	115	94.1	9.9
Ghana	59	8	34	103	72.9	15.8
Greece	170	42	48	115	80.8	15.2
Guatemala	12	7	47	106	75.2	20.9
Hong Kong SAR	6	1	67	105	92.3	13.1
Hungary	3	2	76	95	83.0	10.4
India	279	81	51	115	92.4	12.9
Indonesia	24	11	68	106	81.1	10.9
Iran (Islamic Republic of)	36	18	52	106	75.3	12.6
Iraq	22	13	56	87	72.8	8.9
Ireland	36	12	62	108	86.2	10.4
Israel	9	3	88	113	100.3	7.6
Italy	492	129	48	115	84.7	14.0
Japan	26	19	59	110	83.5	14.1
Jordan	80	18	49	115	86.3	13.9
Kazakhstan	12	6	66	98	82.8	11.1
Kenya	8	6	61	102	88.8	14.2
Kuwait	2	2	73	90	81.5	12.0
Latvia	5	3	73	106	88.0	12.3
Lebanon	14	9	63	98	81.1	11.0
Libya	126	28	28	94	61.7	13.2
Lithuania	10	6	82	113	95.0	12.7
Madagascar	2	1	64	104	84.0	28.3
Malawi	1	1	80	80	80.0	NA
Malaysia	57	23	60	106	84.1	11.2
Malta	3	1	79	90	85.7	5.9
Mexico	62	24	46	115	80.7	16.1
Moldova (the Republic of)	4	2	57	96	68.5	18.4
Mongolia	4	1	43	85	57.8	19.0
Morocco	20	7	55	100	79.7	13.4
Nepal	3	3	80	90	85.7	5.1
Netherlands (the)	18	10	74	114	98.3	12.1
New Zealand	16	11	66	97	79.4	10.4
Nicaragua	1	1	99	99	99.0	NA
Niger (the)	1	1	65	65	65.0	NA
Nigeria	212	31	39	113	74.5	15.1
Norway	2	1	79	105	92.0	18.4
Oman	9	2	71	99	87.9	8.2

Pakistan	118	43	38	115	81.7	16.4
Palestine, State of	58	15	46	114	74.9	11.9
Panama	5	3	65	112	93.2	17.5
Paraguay	14	6	51	97	67.8	15.7
Peru	16	10	49	94	68.1	14.0
Philippines (the)	17	8	65	105	88.9	11.0
Poland	9	5	72	99	85.7	9.7
Portugal	30	14	59	105	85.4	11.0
Qatar	11	2	86	114	99.8	11.2
Republic of North Macedonia	32	10	61	114	84.8	14.2
Romania	44	16	52	114	89.2	14.8
Russian Federation (the)	28	17	55	97	79.0	11.3
Rwanda	11	6	66	113	84.5	14.1
Saint Kitts and Nevis	1	1	54	54	54.0	NA
Saudi Arabia	94	23	58	115	89.5	14.7
Senegal	3	2	68	68	68.0	0.0
Serbia	54	16	51	112	87.3	15.0
Singapore	15	6	87	114	104.7	6.8
Slovakia	5	2	66	100	77.8	12.9
Slovenia	11	2	80	111	94.5	9.4
Somalia	5	1	45	74	62.6	11.2
South Africa	11	6	70	99	81.0	10.2
Spain	258	82	59	115	89.2	11.1
Sri Lanka	14	7	65	109	81.5	11.5
Sudan (the)	58	21	39	95	65.0	14.8
Sweden	15	9	83	112	91.8	7.6
Switzerland	38	9	69	115	95.5	9.7
Syrian Arab Republic	63	9	28	99	69.5	11.1
Taiwan (Province of China)	4	2	84	101	92.3	7.1
Thailand	6	3	97	115	106.8	8.2
Trinidad and Tobago	2	2	42	86	64.0	31.1
Tunisia	9	6	61	92	78.8	10.1
Turkey	139	48	67	115	92.6	11.3
Uganda	12	8	31	88	64.0	16.6
Ukraine	3	2	69	97	82.0	14.1
United Arab Emirates (the)	16	6	88	115	101.3	6.7
United Kingdom of Great Britain and Northern Ireland (the)	510	177	26	115	88.7	11.4
United States of America (the)	135	78	62	115	98.9	10.4
Uruguay	9	3	79	96	89.8	5.8
Venezuela (Bolivarian Republic of)	1	1	35	35	35.0	NA
Yemen	37	5	43	86	62.6	12.5
Zambia	3	2	54	69	61.3	7.5
Zimbabwe	16	5	38	79	56.9	11.2

*The GlobalSurg and CovidSurg networks take an apolitical stance on naming countries and territories here that are non-sovereign or self-declared. In an attempt to create a degree of standardisation we adopted the United Nations' official list of countries and territories, limited to investigators by a prespecified list. Please note that we are not attempting to justify sovereign vs non-sovereign states but simply wish to advance knowledge across countries and regions as self-identified by participants.

Supplementary table 6. Features of hospital assessors

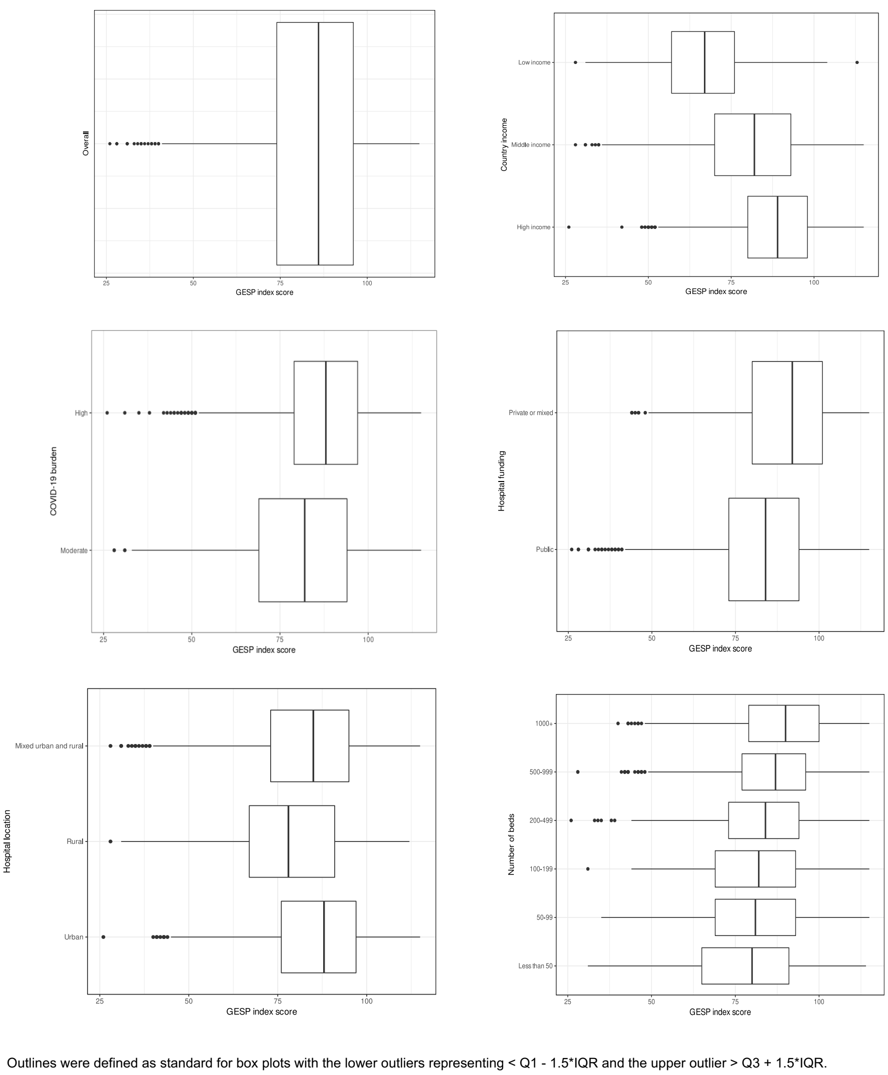
Factor	Level	World Bank income group			Total
		High	Middle	Low	Total
		N=2454	N=2029	N=231	N=4714
Gender	Male	1779 (72.5)	1487 (73.3)	174 (75.3)	3440 (73.0)
	Female	670 (27.3)	539 (26.6)	57 (24.7)	1266 (26.9)
	Non-binary	5 (0.2)	0 (0.0)	0 (0.0)	5 (0.1)
	(Missing)	0 (0.0)	3 (0.1)	0 (0.0)	3 (0.1)
Primary specialty area	Acute care surgery	138 (5.6)	69 (3.4)	8 (3.5)	215 (4.6)
	Breast surgery	65 (2.6)	53 (2.6)	1 (0.4)	119 (2.5)
	Cardiac surgery	64 (2.6)	56 (2.8)	5 (2.2)	125 (2.7)
	Colorectal surgery	369 (15.0)	149 (7.3)	8 (3.5)	526 (11.2)
	Endocrine surgery	34 (1.4)	41 (2.0)	1 (0.4)	76 (1.6)
	Non-specialised general surgery	406 (16.5)	559 (27.6)	112 (48.5)	1077 (22.8)
	Gynaecology	107 (4.4)	92 (4.5)	7 (3.0)	206 (4.4)
	Hepatobiliary surgery	105 (4.3)	64 (3.2)	3 (1.3)	172 (3.6)
	Hernia surgery	9 (0.4)	27 (1.3)	3 (1.3)	39 (0.8)
	Neurosurgery	105 (4.3)	90 (4.4)	20 (8.7)	215 (4.6)
	Obstetrics	21 (0.9)	65 (3.2)	8 (3.5)	94 (2.0)
	Oesophagogastric surgery	94 (3.8)	23 (1.1)	0 (0.0)	117 (2.5)
	Ophthalmology	35 (1.4)	40 (2.0)	9 (3.9)	84 (1.8)
	Oral and maxillofacial surgery	61 (2.5)	32 (1.6)	0 (0.0)	93 (2.0)
	Elective orthopaedics	81 (3.3)	33 (1.6)	0 (0.0)	114 (2.4)
	Orthopaedic trauma surgery	181 (7.4)	103 (5.1)	16 (6.9)	300 (6.4)
	Otolaryngology	111 (4.5)	82 (4.0)	5 (2.2)	198 (4.2)
	Paediatric surgery	93 (3.8)	123 (6.1)	3 (1.3)	219 (4.6)
	Plastic surgery	52 (2.1)	48 (2.4)	6 (2.6)	106 (2.2)
	Surgical oncology	84 (3.4)	118 (5.8)	3 (1.3)	205 (4.3)
	Thoracic surgery	62 (2.5)	34 (1.7)	1 (0.4)	97 (2.1)
	Transplant surgery	28 (1.1)	17 (0.8)	0 (0.0)	45 (1.0)
	Urology	74 (3.0)	73 (3.6)	7 (3.0)	154 (3.3)
	Vascular surgery	74 (3.0)	32 (1.6)	2 (0.9)	108 (2.3)
	Missing	1 (0.0)	6 (0.3)	3 (1.3)	10 (0.2)
Assessor	Surgeon	1550 (63.2)	1212 (59.7)	83 (35.9)	2845 (60.4)
	Surgical trainee	682 (27.8)	492 (24.2)	100 (43.3)	1274 (27.0)
	Anaesthetist/critical care consultant	133 (5.4)	123 (6.1)	8 (3.5)	264 (5.6)
	Anaesthetist/critical care trainee	13 (0.5)	45 (2.2)	5 (2.2)	63 (1.3)
	Nurse	11 (0.4)	30 (1.5)	7 (3.0)	48 (1.0)
	Hospital manager	54 (2.2)	96 (4.7)	19 (8.2)	169 (3.6)
	Non-clinical researcher	32 (1.3)	58 (2.9)	14 (6.1)	104 (2.2)
	Other	137 (5.6)	226 (11.1)	54 (23.4)	417 (8.8)

Supplementary table 7. Hospital and health system factors associated with planned Surgical Volume Ratio (SVR) during COVID-19

Factor	Levels	Estimate	95% confidence interval		P-value
			Lower	Upper	
Intercept	-	87.44	78.83	96.04	*<0.0001*
Surgical Preparedness Index*	Point score	0.35	0.30	0.41	*<0.0001*
Oxford COVID-19 government response index$	Point score	-0.56	-0.64	-0.48	*<0.0001*
Country income	High income	Reference	-	-	-
	Middle income	-8.37	-8.45	-8.29	*<0.0001*
	Low income	-10.56	-14.89	-6.22	*<0.0001*
Hospital funding	Public	Reference	-	-	-
	Private	6.17	3.29	9.05	*<0.0001*
	Mixed public and private	3.96	1.82	6.10	*0.0002*
Surgical service provision	Planned only	Reference	-	-	-
	Planned and unplanned	-4.56	-8.81	-0.31	*0.035*
Hospital location	Urban	Reference	-	-	-
	Rural	2.23	-3.09	7.56	0.411
	Mixed urban and rural	-0.01	-1.56	1.54	0.989
Number of beds	<50	Reference	-	-	-
	50-99	2.23	-2.66	7.11	0.372
	100-199	3.04	-1.47	7.55	0.187
	200-499	3.05	-0.97	7.08	0.137
	500-999	3.41	-0.62	7.44	0.097
	≥1000	4.24	0.07	8.42	*0.046*

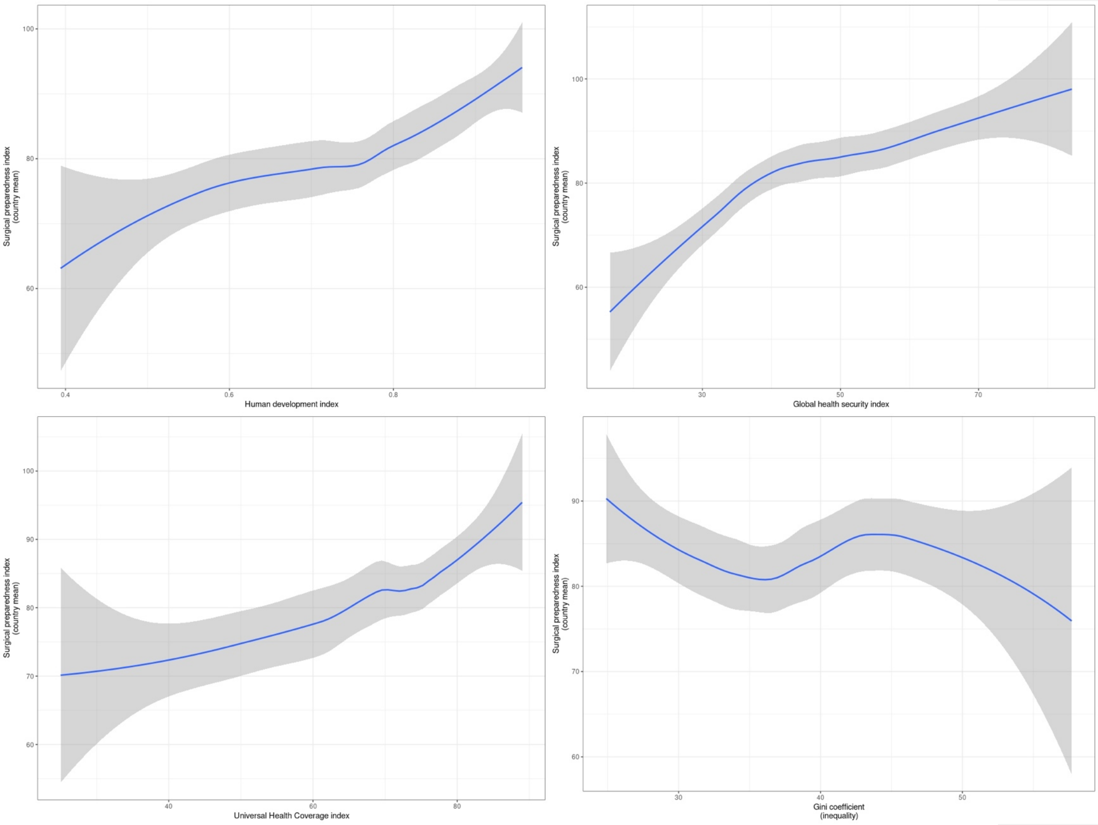
Estimate of the intercept value, and beta-coefficients for each factor / levels in the mixed effects linear regression model. *Surgical preparedness index (SPI) score is made up of 23 indicators, each scored between 1 (very weak) and 5 (very strong). The sum score values range between 23 and 115. $Oxford COVID-19 government response index contains 17 indicators around four themes of closure and containment, health, and economic support with a normalised range between 0 (no government response) and 100 (most stringent government response). A directed acyclic graph displaying proposed causal relationships is presented in Figure 6.

Supplementary figure 1. Distribution of Surgical Preparedness Index (SPI) scores across key subgroups



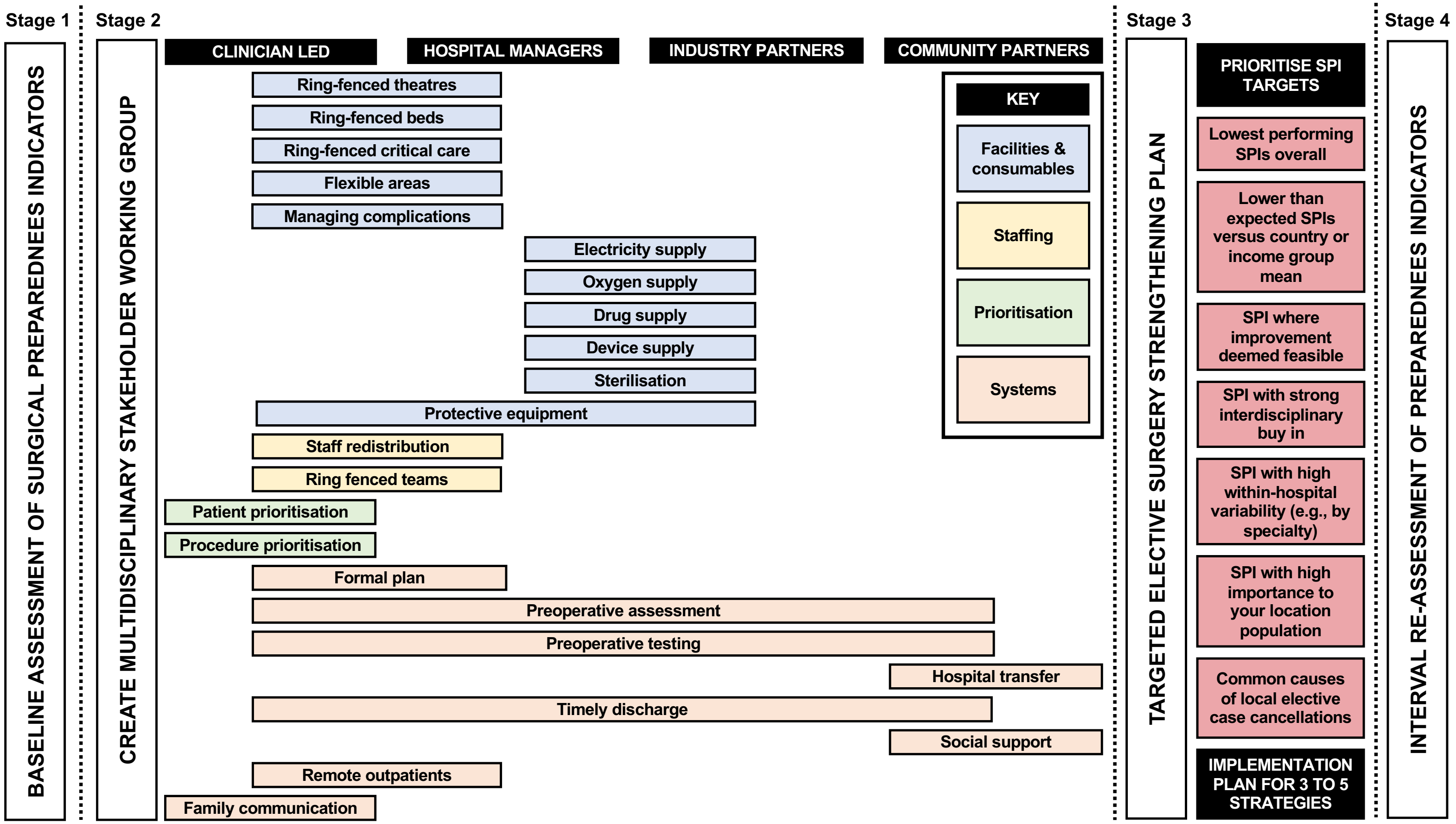
Outlines were defined as standard for box plots with the lower outliers representing < Q1 - 1.5*IQR and the upper outlier > Q3 + 1.5*IQR.

Supplementary figure 2. Relationship between Surgical Preparedness Index (SPI) and other global health indicators

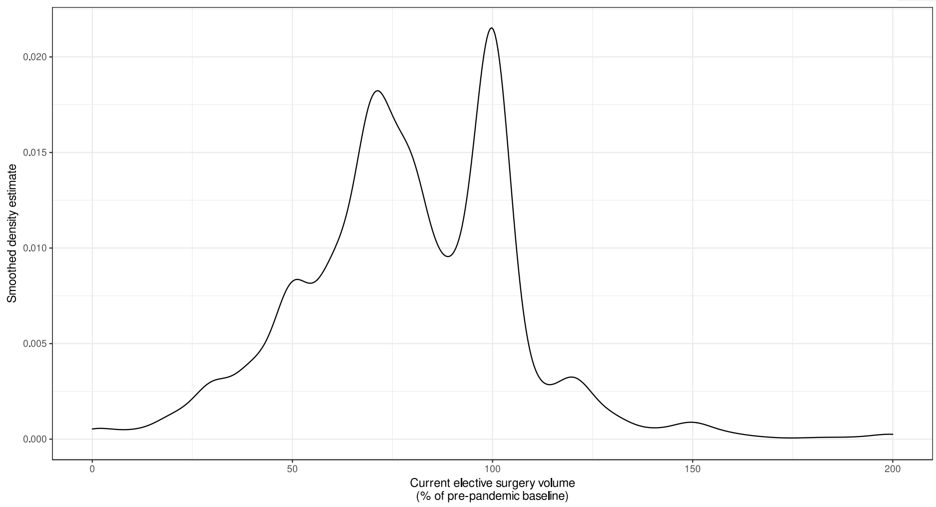


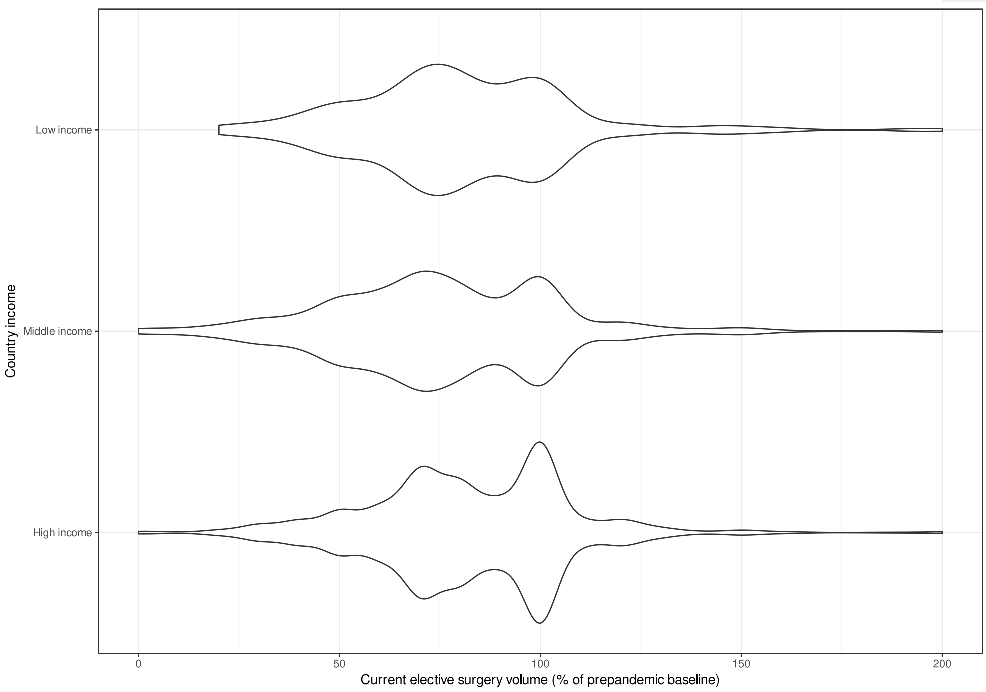
We present the relationship between national mean SPI scores and four relevant global health indicators: (1) United Nation's Human development index, which is a composite index of life expectancy, education and per capita income. A higher HDI score indicates greater development; (2) Global health security index which is an assessment of global health security capabilities (i.e., a measure of whole health-system resilience) from the Johns Hopkins Center for Health Security, the Nuclear Threat Initiative (NTI) and the Economist Intelligence Unit (EIU). A high GHS score indicates a more resilient health system; (3) World Health Organization Universal Health Coverage (UHC) service coverage index, which combines 14 tracer indicators of service coverage into a single summary measure. A higher UHC index indicates greater coverage; (4) Gini coefficient which is a measure of population wealth inequality. A Gini coefficient of 0 expresses perfect equality whilst 1 indicates maximal inequality.

Supplementary figure 3. Suggested implementation framework for hospital-level surgical and anaesthesia service strengthening

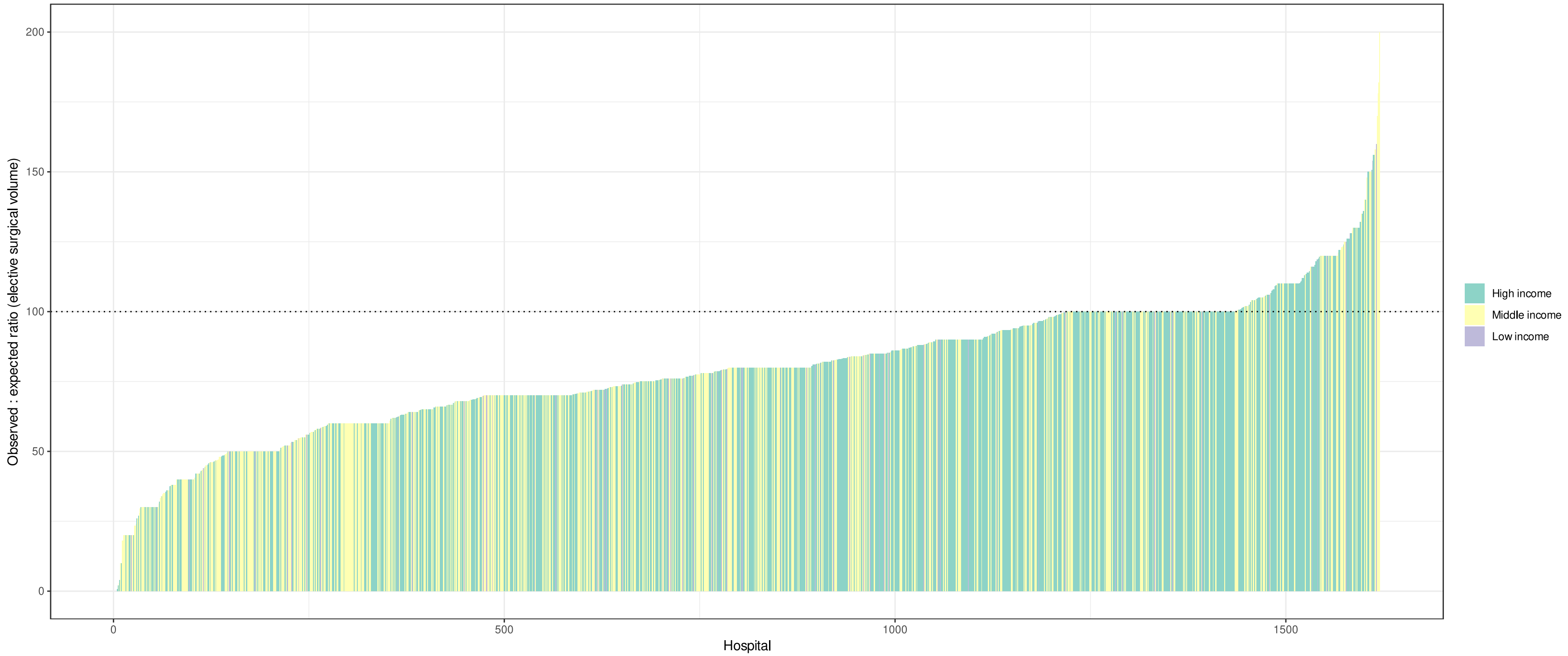


Supplementary figure 4. Surgical volume ratio overall and by country income group



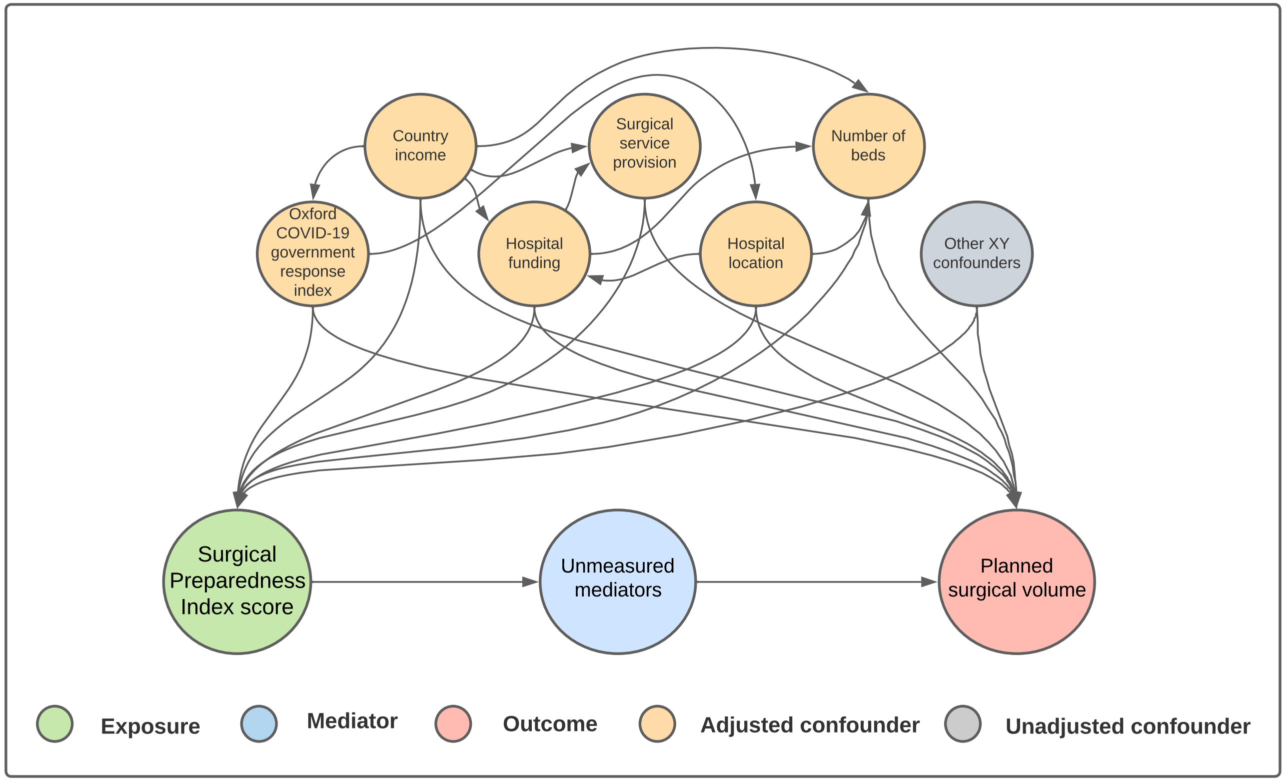


Supplementary figure 5. Variability in ability of hospitals to maintain their planned Surgery Volume Ratio (SVR) during the SARS-CoV-2 pandemic



Each vertical bar represents a participating hospital. Dotted line demonstrates where the observed planned case volume was as expected based on the same 1-month assessment period in 2019 (SVR = 100%). Hospitals from low, middle and high-income countries demonstrated low, moderate and high ability to maintain their planned SVR, indicating that preparedness was not a function of health system resourcing / country income alone.

Supplementary figure 6. Directed Acyclic Graph (DAG) displaying causal model linking the Surgical Preparedness Index to planned surgical volume



Arrows indicate the direction of hypothesised casual relationships adopting in the mixed-effects linear regression modelling.

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Appendix B. Full methodology for the international consultation process

The overall methodology and results for the consultation process using a Delphi consensus methodology are summarised in Figure 1.

Longlisting

During longlisting, the international index development group (IIDG) were asked to submit potential indicators for inclusion during the longlisting process. They were asked to consider features of their local hospitals that they thought were plausibly associated with that hospital's ability (or lack thereof) to maintain capacity for planned surgery during periods of external system 'shock', using the SARS-CoV-2 pandemic as a key exemplar. The free-text responses underwent thematic content analysis with double coding by two independent researchers (JG, JS) to identify distinct indicators. These were then compared and combined where themes overlapping, with care not to lose meaning. Where any uncertainty existed with overlapping themes the perspective of the submitting development group member was sought and a final decision was made with the support of a third researcher (AB). Additional indicators were extracted from relevant systematic review, indicator, and framework development studies for whole health-system resilience (11, 30, 41, 42). All candidate indicators identified in this thematic analysis were included in Round 1 electronic voting.

Round 1. Electronic voting round

In Round 1, candidate indicators were added to an online questionnaire hosted in an electronic data capture system (REDCap) at the University of Birmingham. All response data to the prioritisation survey was stored on encrypted, secure Research Electronic Data Capture (REDCap) server hosted by the NIHR Global Health Research in Global Surgery at the University of Birmingham. Data were anonymised before analysis and held in accordance with EU General Data Protection Regulation (GDPR) recommendations.

Indicators were presented in a different random order to each participant to minimise primacy bias. Round voting was distributed to the existing IIDG. The purpose of the voting in Round 1 was to screen out candidate indicators that were not deemed to be important, not easy to measure, and to identify indicators that required re-wording to improve their clarity and global relevance. Respondents were asked two questions about each indicator with a continuous item response variable:

(1) Whether the indicator was important to hospital preparedness (0 = not at all important, 100 = very important)
(2) Whether the indicator would be easy to measure (0 = very difficult to measure, 100 = very easy to measure)

Dropping rules for indicators were predefined; if an indicator had a mean overall importance rating of <70 or ease of measurement <70 it continued moved into Round 2 discussion, and Round 3 voting. If an indicator had a mean overall importance and ease of measurement it was accepted into the SPI and underwent refinement during Round 4 discussion.

Round 2. Virtual focus group meeting with IIDG

Round 1 voting results were reviewed by the IIDG at virtual focus group meeting using Zoom (Zoom corporation®, Chiyoda City, Tokyo, Japan) on 23 March 2021. The panel were asked to specifically re-considered whether the indicators were likely contribute to hospitals' ability to maintain planned surgery volume (preparedness as defined in this study), and whether voting reflected any inconsistency or uncertainty in the item wording. Free-text responses were used to iteratively refine indicators to improve clarity and consistency for an international audience. For each draft indicator the panel formed a consensus on which of the following decisions to take:

- To accept it with its current wording.

- To accept it following re-wording aimed at either reducing its ambiguity, or maximising its relevance. When appropriate, the panel combined separate draft statements into single indicators.
- To eliminate it entirely.

The refined indicator set were moved into Round 3 voting.

Round 3. Electronic voting round

Round 3 consensus voting which was also performed online using REDCap and was closed survey distributed to all respondents to Round 1 voting. Respondents indicated whether they perceived the indicator to be essential (baseline measures that should be implemented as a priority), desirable (some hospitals may lack relevant resources at present, in which case they should plan for future implementation) or remove (not essential to hospital preparedness, or too challenging to implement). Where greater than 50% of respondents voted an indicator to be essential, this was included in the final SPI. Where more than 10% of respondents voted for an indicator to be removed, this was dropped. Where indicators did not meet either of these thresholds they went on to further discussion in the Round 4 focus group.

Round 4. Virtual focus group meeting with IIDG

Round 3 voting results were again reviewed by the IIDG at virtual focus group meeting on 12 May 2021. For indicators that had not yet reached a threshold, the panel formed a consensus on whether:

- To accept it with its current wording.
- To accept it following re-wording aimed at either reducing its ambiguity, or maximising its relevance.
- To eliminate it.

Free text responses were again used to continue iterative development of the overall indicator set. The final SPI was agreed by the IIDG, and continued into the hospital assessment phase. In this phase the development group also considered how they would rate the strength of a local surgical system in accordance with each indicator. After an ideas generation phase, these were clarified and refined, before the group made a pragmatic decision on item responses and scaling to be adopted in hospital assessment.