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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.

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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 perioud	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

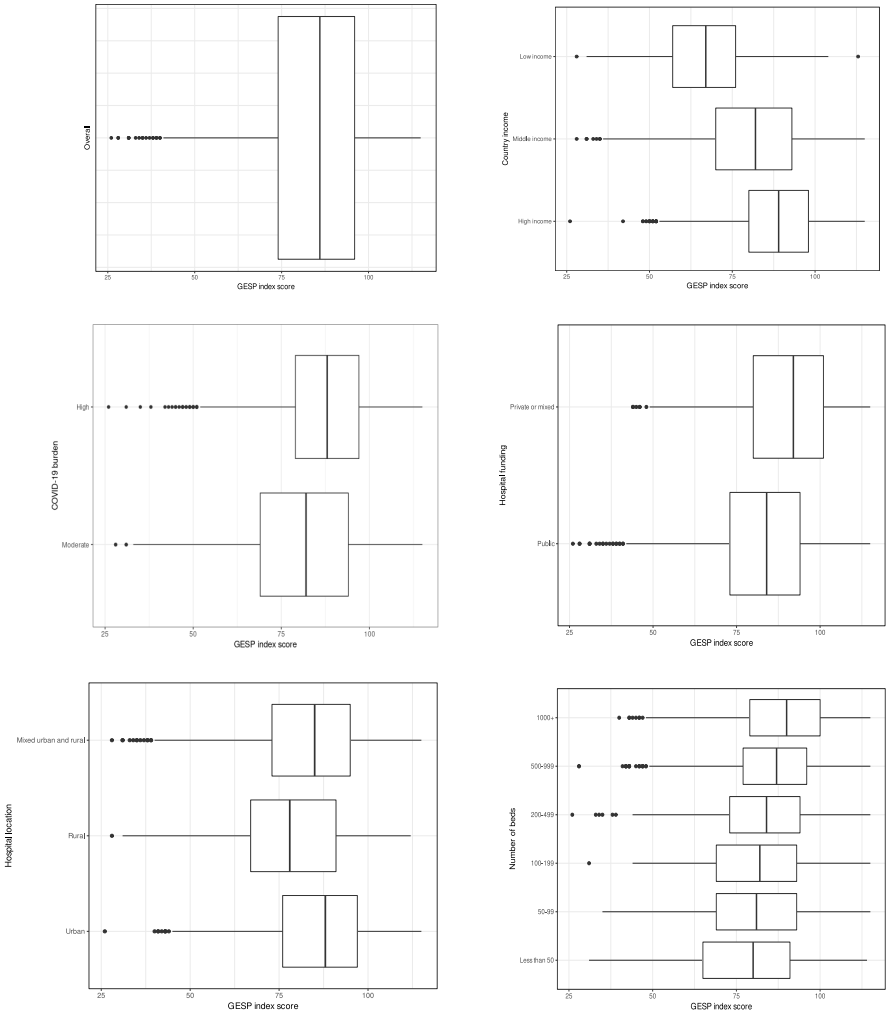
Factor	Level	World Bank income group			
		High	Middle	Low	Total
		N=2454	N=2029	N=231	N=4714
Gender	Male	1779 (72.5)	1487 (73.3)	174 (75.3)	3440 (73.0)
	Female	670 (27.3)	539 (26.6)	57 (24.7)	1266 (26.9)
	Non-binary	5 (0.2)	0 (0.0)	0 (0.0)	5 (0.1)
	(Missing)	0 (0.0)	3 (0.1)	0 (0.0)	3 (0.1)
Primary specialty 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

			95% confidence interval		
Factor	**Levels**	**Estimate**	**Lower**	**Upper**	**P-value**
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*

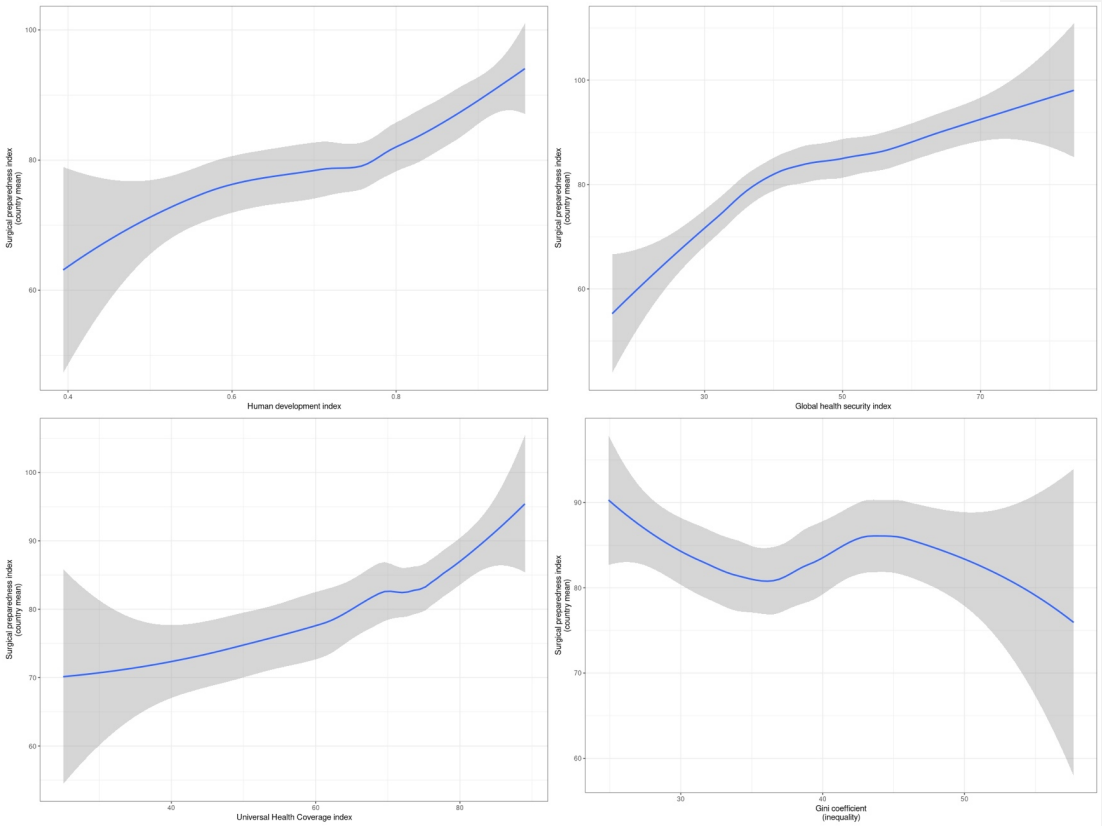
Estimate of the intercept value, and beta-coefficients for each factor / levels in the mixed effects linear regression model. *Surgical preparedness index (SPI) score is made up of 23 indicators, each scored between 1 (very weak) and 5 (very strong). The sum score values range between 23 and 115. [$]Oxford 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



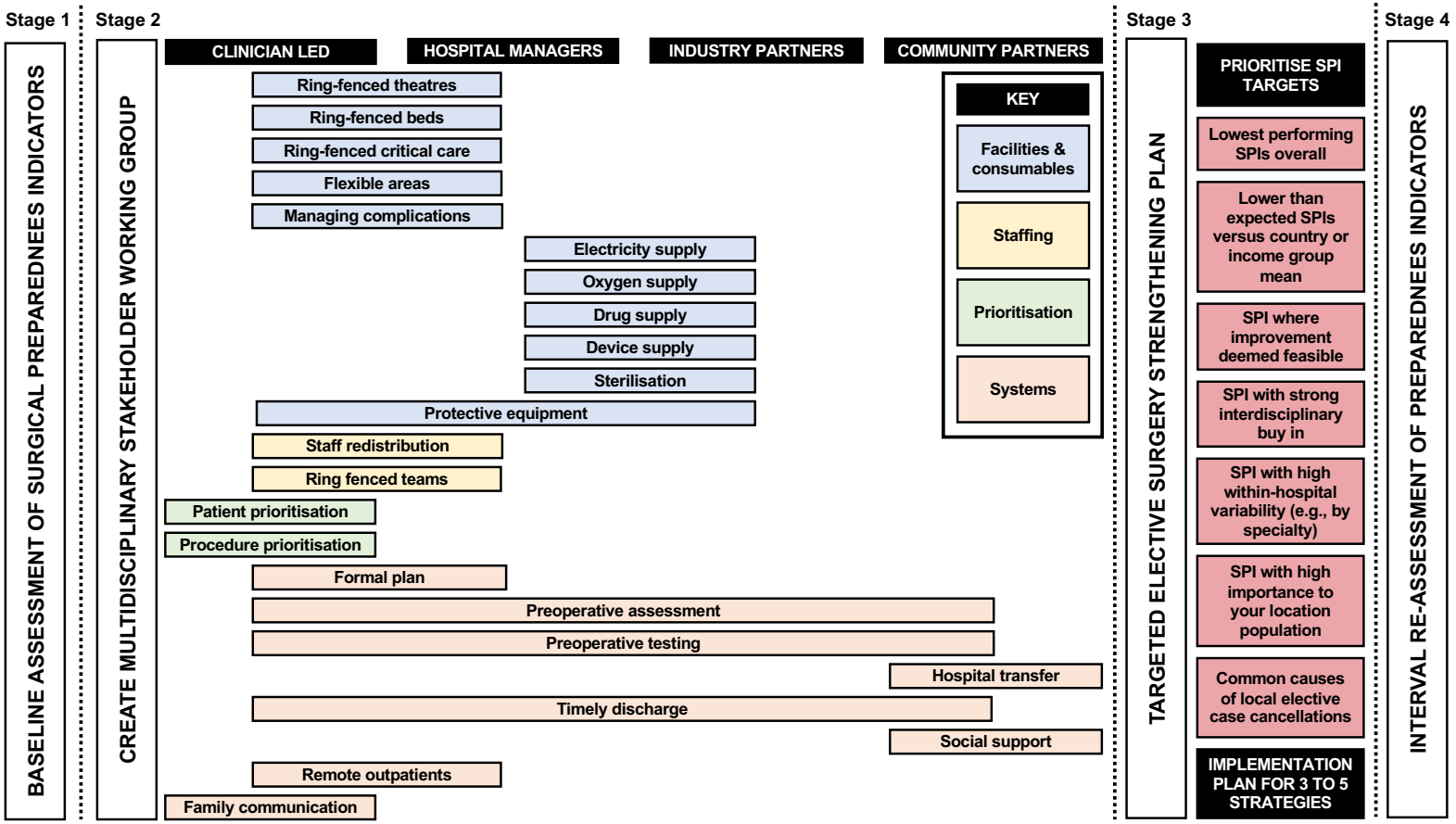
Outlines were defined as standard for box plots with the lower outliers representing < Q1 - 1.5*IQR and the upper outlier > Q3 + 1.5*IQR.

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

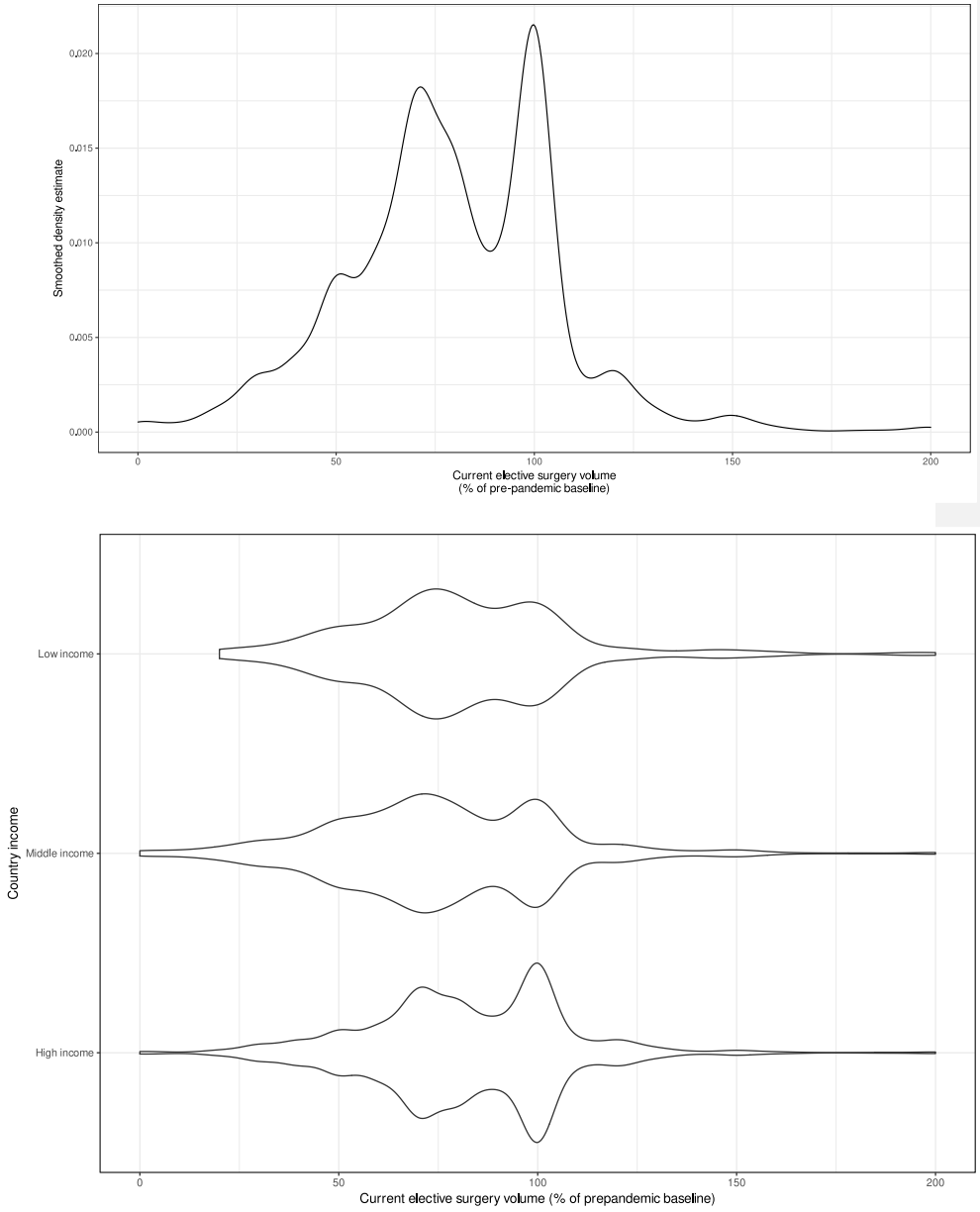


We present the relationship between national mean SPI scores and four relevant global health indicators: (1) United Nation's Human development index, which is a composite index of life expectancy, education and per capita income. A higher HDI score indicates greater development; (2) Global health security 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.

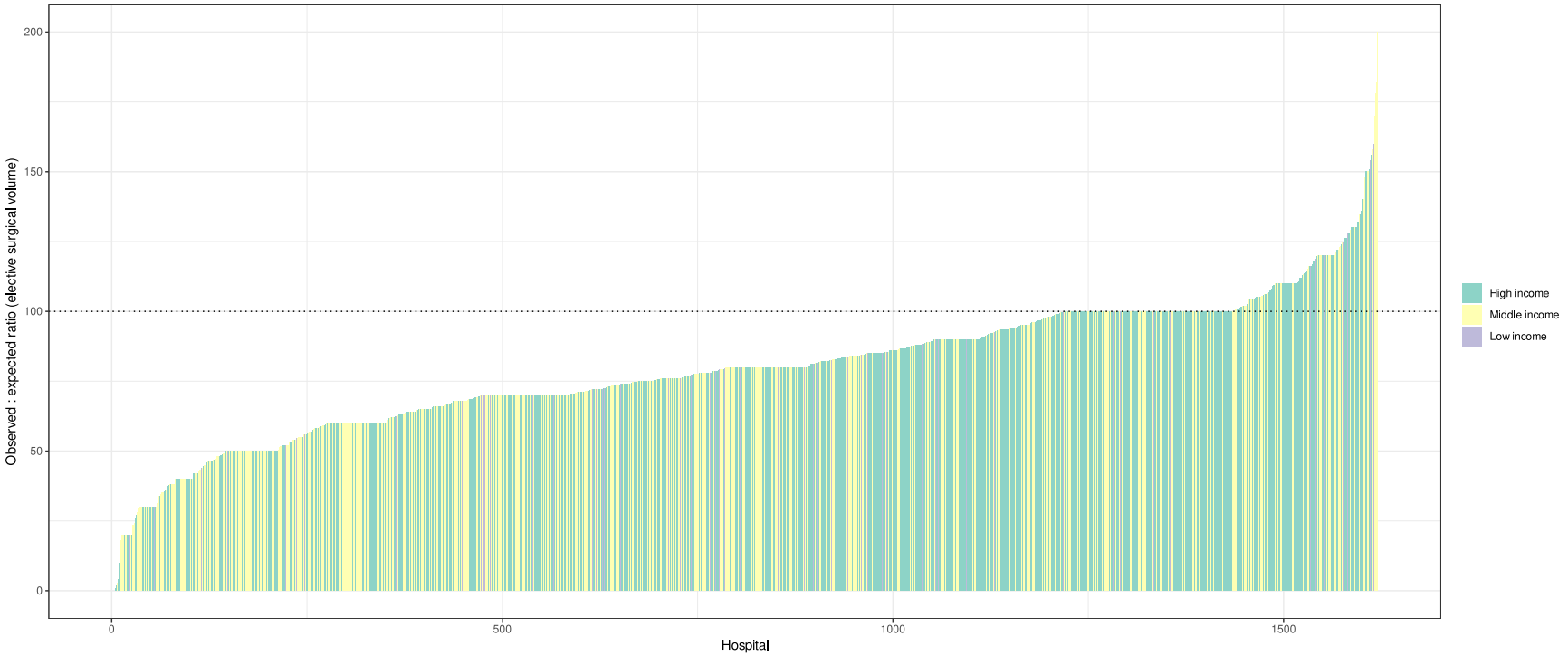
Supplementary figure 3. Suggested implementation framework for hospital-level surgical and anaesthesia service strengthening



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

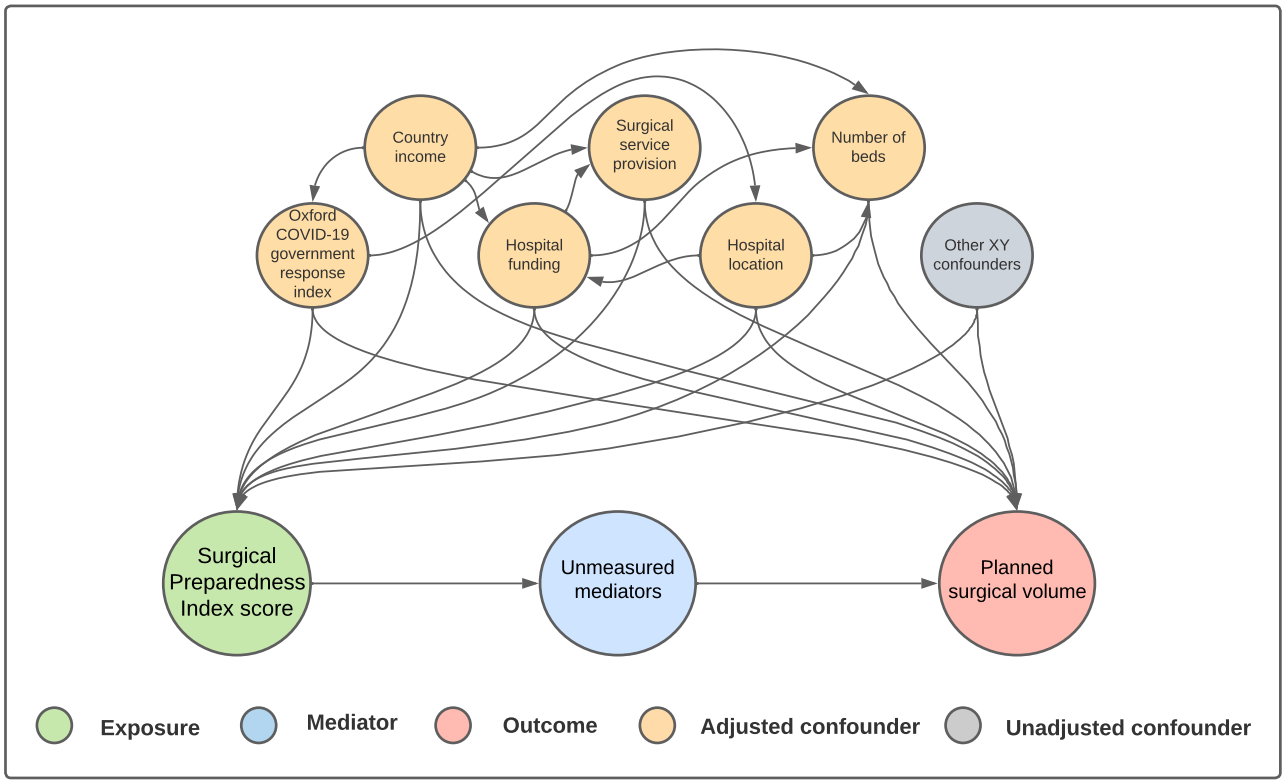


Supplementary figure 5. Variability in ability of hospitals to maintain their planned Surgery Volume Ratio (SVR) during the SARS-CoV-2 pandemic



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.