Mortality after surgery with SARS-CoV-2 infection in England: a population-wide epidemiological study

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Abstract

Background: The COVID-19 pandemic has heavily impacted elective and emergency surgery around the world. We aimed to confirm the incidence of perioperative severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection and associated mortality after surgery.

Methods: Analysis of routine electronic health record data from NHS hospitals in England. We extracted data from Hospital Episode Statistics in England describing adult patients undergoing surgery between January 1, 2020 and February 28, 2021. The exposure was SARS-CoV-2 infection defined by International Classification of Diseases (ICD)-10 codes. The primary outcome measure was 90 day in-hospital mortality. Data were analysed using multivariable logistic regression adjusted for age, sex, Charlson Comorbidity Index, Index of Multiple Deprivation, presence of cancer, surgical procedure type and admission acuity. Results are presented as *n* (%) and odds ratios (OR) with 95% confidence intervals (CI).

Results: We identified 2 666 978 patients undergoing surgery of whom 28 777 (1.1%) had SARS-CoV-2 infection. In total, 26 364 (1.0%) patients died in hospital. SARS-CoV-2 infection was associated with a much greater risk of death (SARS-CoV-2: 6153/28 777 [21.4%] *vs* no SARS-CoV-2: 20 211/2 638 201 [0.8%]; OR=5.7 [95% CI, 5.5–5.9]; *P*<0.001). Amongst patients undergoing elective surgery, 2412/1 857 586 (0.1%) had SARS-CoV-2, of whom 172/2412 (7.1%) died, compared with 1414/1 857 586 (0.1%) patients without SARS-CoV-2 (OR=25.8 [95% CI, 21.7–30.9]; *P*<0.001). Amongst patients undergoing emergency surgery, 22 918/582 292 (3.9%) patients had SARS-CoV-2, of whom 5752/22 918 (25.1%) died, compared with 18 060/559 374 (3.4%) patients without SARS-CoV-2 (OR=5.5 [95% CI, 5.3–5.7]; *P*<0.001).

Conclusions: The low incidence of SARS-CoV-2 infection in NHS surgical pathways suggests current infection prevention and control policies are highly effective. However, the high mortality amongst patients with SARS-CoV-2 suggests these precautions cannot be safely relaxed.

Keywords: anaesthesia; COVID-19; epidemiology; public policy; surgery

Editor's key points

- Patients with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection undergoing surgery have much higher risk of severe post-operative respiratory complications and death.
- This study found that 1 in 100 surgical patients were infected by SARS-CoV-2 in the English NHS through 2020, most of whom had required emergency surgery.
- Elective surgical patients who developed SARS-CoV-2 infection were 25 times more likely to die while in hospital.
- Strict, additional infection prevention and control procedures are crucially important for perioperative care during a pandemic.

Surgery is an essential treatment modality with more than 330 million surgical procedures performed worldwide every year.[1–3] However, the COVID-19 pandemic has led to substantial reductions in the volume of surgery performed.[4,5] Recent estimates suggest that half of the 4.5 million expected surgical procedures in the English NHS were cancelled or postponed in 2020.[4] This is partly driven by reallocation of resources to care for patients with COVID-19, but also by strict infection prevention and control procedures implemented to prevent patients becoming infected with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) while in hospital.[6] Patient self-isolation before surgery, preoperative testing for SARS-CoV-2, creation of separate 'green zones' in hospitals to isolate non-infected patients, and personal protective equipment procedures all contribute to reductions in the efficiency of surgical care pathways, and substantial reductions in the volume of patients treated.[7]

Early reports have suggested that patients with SARS-CoV-2 infection who undergo surgery are at much greater risk of postoperative pulmonary complications and death.[8,9] The COVIDSurg Collaborative undertook a large international study of outcomes for surgical patients infected with SARS-CoV-2 and reported mortality rates as high as 24% at the peak of the pandemic.[8] However, more recent data suggest the mortality risk for surgical patients with SARS-CoV-2 may be lower than originally thought,[9] especially for minor surgery in younger patients.[10] It remains unclear how SARS-CoV-2 infection affects outcomes after surgery, and whether high mortality rates reported in some studies relate to a change in surgical case mix during the pandemic, or to SARS-CoV-2 infection itself. At present there are no large studies describing surgical outcomes for contemporaneous patient groups with and without SARS-CoV-2 infection. Given the extensive disruption to surgical services and the likely excess mortality owing to untreated cancer and other surgical diseases, the NHS is under significant pressure to relax infection prevention and control procedures to increase the volume of patients who can undergo surgery.

We used routine NHS electronic health record data to report the rate of SARS-CoV-2 infection amongst surgical patients during the pandemic, and the associated mortality and hospital stay.

Methods

Study design

Population-wide epidemiological study using routinely collected electronic health record data.

Setting

NHS hospitals in England.

Participants

All patients aged 18 yr or older who underwent a surgical procedure between January 1 and February 28, 2021.

Data source

We used pseudonymised record level Hospital Episode Statistics (HES) to identify eligible patients. This data source provides detailed data describing every episode of hospital care in England. Surgical procedures were identified using Office for Population Censuses Surveys version 4 (OPCS4) codes as described previously.[2,4] These define procedures typically performed in an operating theatre or under general/regional anaesthesia (Appendix A). Individuals entered the cohort on the date of their first operative procedure and were followed until the point of hospital discharge. Hospital discharge date was determined based on the discharge from continuous in-patient stays, which were constructed by mapping continuous in-patient episodes.[11] For patients remaining in hospital, their discharge date was right censored to February 28, 2021. The analysis was approved by the Health Research Authority (20/HRA/3121) and the NHS Digital Independent Group Advising on the Release of Data (DARS-NIC-375669-J7M7F).

Exposure

The exposure of interest was a diagnosis of SARS-CoV-2 viral infection defined using the following International Classification of Diseases (ICD)-10 codes: U07.1 (Virus identified), U07.2 (Virus not identified) or B97.2 (Other coronavirus as the cause of diseases classified elsewhere). Patients with SARS-CoV-2 were categorised as symptomatic if they had ICD-10 codes for concomitant respiratory illness or OPCS-4 codes indicating respiratory support (Supplementary Table S1). Patients with SARS-CoV-2 were categorised as not symptomatic if there were no associated ICD-10 codes for respiratory illness or OPCS-4 codes for respiratory support. We divided the exposure into three time points: preoperative if SARS-CoV-2 codes were first recorded in an episode that finished within the 30 days before the index operation; perioperative if a code was first recorded in the same episode as the index operation; and postoperative if a code was first recorded in a subsequent healthcare episode before discharge within 30 days after the index operation.

Outcomes

The primary outcome was in-hospital death, censored at 90 days for patients remaining in hospital beyond this point. The secondary outcome was length of hospital stay, calculated as the number of days between initial operation date and discharge date of their continuous in-patient stay, censored at 90 days.

Derivation of variables

Age was defined as that recorded on the start date of the hospital episode including the first operative procedure. Charlson Comorbidity Index was derived according to the
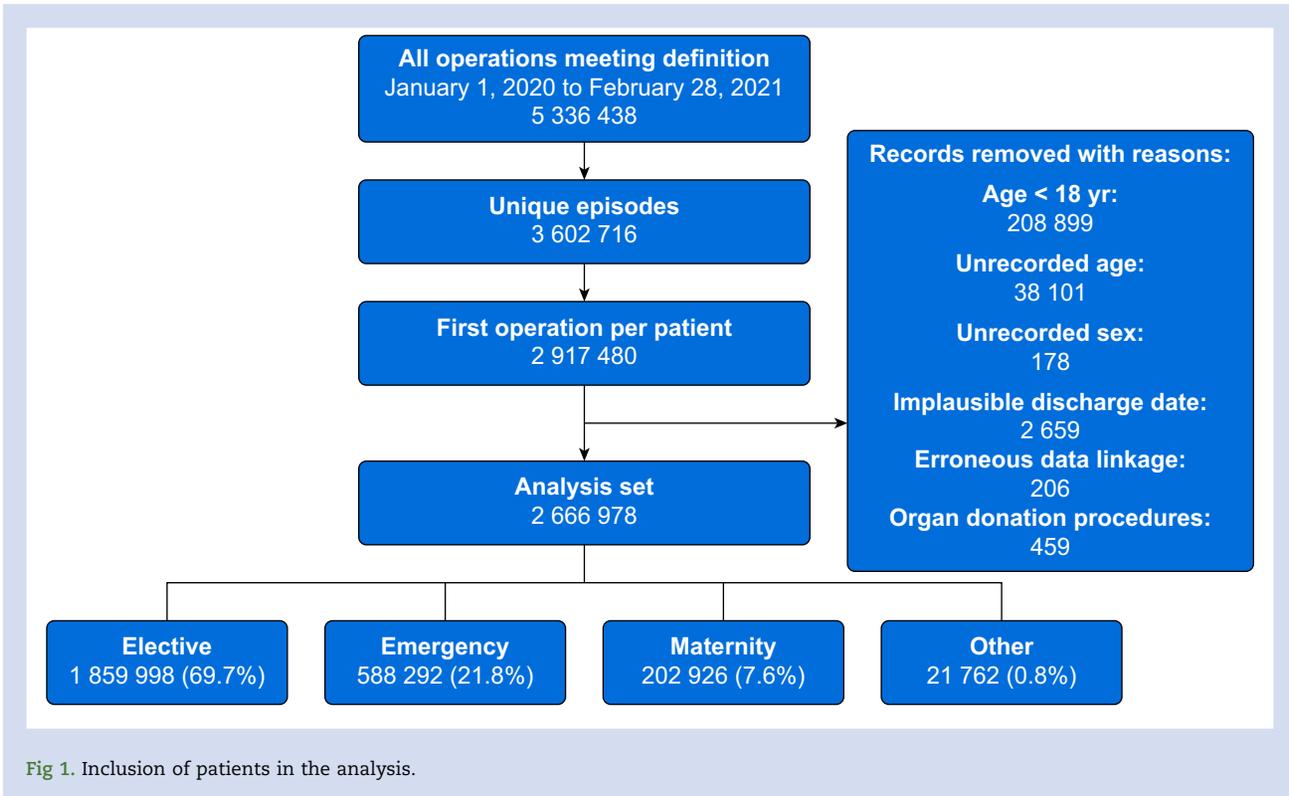
Fig 1. Inclusion of patients in the analysis.

Royal College of Surgeons mapping, which includes a 1 yr look-back file to capture diagnoses from prior admissions.[12] Classification of the type of surgical procedure was based on the first operative code.[4] Where multiple operative codes were associated with surgery on a single day, the highest ranked code was considered the principal surgical procedure. Socio-economic deprivation was defined according to lower super-output areas using the Index of Multiple Deprivation (IMD).[13] We classified missing IMD as its own category.

Statistical methods

The incidence of SARS-CoV-2 infection among patients undergoing surgery was calculated by dividing the number of patients with an ICD-10 code indicating SARS-CoV-2 infection by the total number of patients in the cohort. Age-adjusted incidence was calculated using deciles of age.[14] To test for associations between SARS-CoV-2 infection and in-hospital mortality, we used multivariable logistic regression analysis including the following covariates: age, sex, Charlson Comorbidity Index, IMD, presence of cancer, surgical procedure type, and admission acuity.[15–18] Results are presented as n (%), mean (standard deviation [SD]), median (inter-quartile range), or as odds ratios (OR) with 95% confidence intervals (CI) and P-values. The threshold for statistical significance was $P<0.05$. We undertook two pre-specified sub-group analyses. First, we assessed the risk of mortality among patients with SARS-CoV-2 infection stratified by urgency of surgery (elective surgery or emergency surgery). Second, we compared the risk of mortality among patients with SARS-CoV-2 infection between patients with and without respiratory symptoms. Analyses were conducted using Python (version 3.7.5) and graphs made in R (V4.0.2; R-project, Vienna, Austria).

Sensitivity analysis using laboratory data from NHS Wales

To check the completeness of ICD-10 coding for a positive SARS-CoV-2 diagnosis, we compared reported cases of SARS-CoV-2 infection using ICD-10 codes to the integrated central laboratory records system describing all SARS-CoV-2 test results in Wales, which includes results of tests conducted for Welsh residents from both NHS and private laboratories. SARS-CoV-2 swabs collected from between 30 days before to the end of the index surgical spell were used to identify perioperative SARS-CoV-2. This analysis used pseudonymised record level Patient Episode Database in Wales (PEDW) to identify eligible patients. The project was approved by the Secure Anonymised Information Linkage Databank (SAIL) independent Information Governance Review Panel (Project number: 0911).[19]

Post-hoc sensitivity analysis of hospital readmission and postoperative SARS-CoV-2 infection

Given the long incubation period of SARS-CoV-2 infection, we report the frequency of emergency hospital re-admission in England within 30 days of surgery, stratified by the presence of SARS-CoV-2 infection ICD-10 codes.

Sample size calculation

This was a population-wide cohort study including all patients who underwent surgery in England during the study period. A sample size of 2 million patients, with an allocation ratio of 0.01, and an alpha of 0.05 would give approximately 100% power to detect a 10% difference in the relative risk of mortality among patients with and without SARS-CoV-2 infection.

Table 1 Patient characteristics. Numbers are presented as *n* (%) unless otherwise stated. *Numbers suppressed to maintain patient anonymity. SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; SD, standard deviation; IQR, inter-quartile range; IMD, Index of Multiple Deprivation.

	All patients	SARS-CoV-2 status				
		None	Preoperative	Perioperative	Postoperative	Any time
N	2 666 978	2 638 201 (98.9%)	18 484 (0.7%)	2875 (0.1%)	7418 (0.3%)	28 777 (1.1%)
Age						
Mean (SD)	57 (20)	57 (20)	62 (18)	64 (21)	76 (15)	65 (20)
Median (IQR)	60 (40–74)	60 (40–74)	63 (50–75)	68 (49–81)	79 (68–87)	68 (51–81)
Sex						
Male	1 182 896 (44.4%)	1 168 372 (98.8%)	4279 (0.4%)	8829 (0.7%)	1416 (0.1%)	14 524 (1.2%)
Female	1 483 913 (55.6%)	1 469 660 (99%)	3139 (0.2%)	9655 (0.7%)	1459 (0.1%)	14 253 (1%)
Unspecified	169 (0.0%)	169 (0.0%)	* (%*)	* (%*)	* (%*)	* (%*)
Admission category						
Elective	1 859 998 (69.7%)	1 857 586 (99.9%)	809 (0%)	1456 (0.1%)	147 (0%)	2412 (0.1%)
Emergency	582 292 (21.8%)	559 374 (96.1%)	5543 (1%)	14 721 (2.5%)	2654 (0.5%)	22 918 (3.9%)
Other	21 762 (0.8%)	20 568 (94.5%)	634 (2.9%)	491 (2.3%)	69 (0.3%)	1194 (5.5%)
Maternity	202 926 (7.6%)	200 673 (98.9%)	432 (0.2%)	1816 (0.9%)	* (%*)	2253 (1.1%)
Inpatient/day-case						
Inpatient	1 343 864 (50.4%)	1 315 606 (97.9%)	7049 (0.5%)	18 337 (1.4%)	2872 (0.2%)	28 258 (2.1%)
Day-case	1 323 114 (49.6%)	1 322 595 (100%)	369 (0%)	147 (0%)	* (%*)	519 (0%)
Charlson Comorbidity Index						
Score >0	1 238 969 (46.5%)	1 217 783 (98.3%)	5781 (0.5%)	12 920 (1%)	2485 (0.2%)	21 186 (1.7%)
Index of Multiple Deprivation						
1 – most deprived	514 727 (19.3%)	507 170 (98.5%)	2109 (0.4%)	4818 (0.9%)	630 (0.1%)	7557 (1.5%)
2	526 432 (19.7%)	520 243 (98.8%)	1680 (0.3%)	3966 (0.8%)	543 (0.1%)	6189 (1.2%)
3	532 351 (20.0%)	526 934 (99%)	1361 (0.3%)	3486 (0.7%)	570 (0.1%)	5417 (1%)
4	534 211 (20.0%)	529 434 (99.1%)	1152 (0.2%)	3075 (0.6%)	550 (0.1%)	4777 (0.9%)
5 – least deprived	532 808 (20.0%)	528 280 (99.2%)	1059 (0.2%)	2918 (0.5%)	551 (0.1%)	4528 (0.8%)
Missing IMD status	26 449 (1.0%)	26 140 (98.8%)	57 (0.2%)	221 (0.8%)	31 (0.1%)	309 (1.2%)

Results

Participants

There were 5 336 438 surgical procedures among 2 917 480 patients in England between January 1, 2020 and February 28, 2021. After predefined exclusions (209 358; 7%) and exclusion of those with missing data (41 144; 1.4%), 2 666 978 patients undergoing surgery were included in the primary analysis (Fig. 1). Demographic data are presented in Table 1. Data are presented according to surgical specialty in Table 2. Demographic data of patients with missing age data are shown in Supplementary Table S2.

Incidence of SARS-CoV-2 among surgical patients

Among 2 666 978 adult patients who underwent surgery, 28 777 (1.1%) had SARS-CoV-2 (Table 1 and Fig. 2). Overall, 15 637/28 777 (54.3%) surgical patients with SARS-CoV-2 infection had respiratory symptoms. The age-adjusted incidence of SARS-CoV-2 infection among surgical patients was 934 infections (95% CI, 899–971) per 100 000.

Patient outcomes

Overall, 26 364/2 666 978 (1.0%) patients who underwent a surgical procedure died. A total of 6153 of 28 777 (21.4%) surgical patients with SARS-CoV-2 infection died compared with 20 211/2 638 201 (0.8%) patients without SARS-CoV-2 infection (Table 3). The adjusted odds of death among surgical patients with SARS-CoV-2 infection compared with surgical patients without infection is 5.7 (95% CI, 5.5–5.9; P<0.001) (Table 4).

Length of hospital stay among patients with and without SARS-CoV-2 infection is presented in Table 3. The survival curves of those with and without SARS-CoV-2 infection are presented in Figure 3.

Urgency of surgery

Amongst patients undergoing elective surgery, 2412/1 859 998 (0.1%) had SARS-CoV-2 infection, of whom 172/2412 (7.1%) died compared with 1414/1 857 586 (0.1%) patients without SARS-CoV-2 infection (Table 3). Therefore, the incidence of death from SARS-CoV-2 infection among elective surgical patients was 172/1 859 998 (0.009%, or 1 in 10 814). The adjusted odds of death among patients undergoing elective surgery with SARS-CoV-2 around the time of surgery is 25.8 (95% CI, 21.7–30.9; P<0.001) (Supplementary Table S3). Amongst patients undergoing emergency surgery, 22 918/582 292 (3.9%) had SARS-CoV-2 infection, of whom 5752/22 918 (25.1%) died compared with 18 060/559 374 (3.2%) patients without SARS-CoV-2 infection. The adjusted odds of death among patients undergoing emergency surgery with SARS-CoV-2 around the time of surgery is 5.5 (95% CI, 5.3–5.7; P<0.001) (Supplementary Table S4).

Symptomatic SARS-CoV-2 infection

Among patients with SARS-CoV-2 infection and respiratory symptoms, 5265/15 637 (33.7%) died compared with 888/13 140 (6.8%) of patients with SARS-CoV-2 infection but no respiratory symptoms recorded (OR=5.5; 95% CI, 5.1–6.0; P<0.001) (Supplementary Tables S5 and S6).

Table 2 Risk of in-hospital mortality stratified by anatomical location of primary procedure. Data presented as *n* (%). *Numbers suppressed to maintain patient anonymity. Risk of in-hospital mortality stratified by surgical specialty. Organ donation removed given low numbers. GI; gastrointestinal; HPB, hepatopancreatobiliary; LGU, lower genitourinary; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; UGU, upper genitourinary.

	SARS-CoV-2 infection		No SARS-CoV-2 infection	
	n	In-hospital death	*n*	In-hospital death
Bone	3417	815 (23.9%)	132 180	1909 (1.4%)
Breast	43	* (%*)	56 450	12 (0.0%)
Cardiac	2374	313 (13.2%)	153 894	2609 (1.7%)
Cerebrovascular	116	21 (18.1%)	4769	211 (4.4%)
Ear	56	10 (17.9%)	27 756	28 (0.1%)
Endocrine	46	* (%*)	14 778	32 (0.2%)
Female LGU	48	* (%*)	24 587	19 (0.1%)
Female UGU	348	* (%*)	128 201	51 (0.0%)
HPB	752	120 (16.0%)	74 445	723 (1.0%)
Joint	3067	755 (24.6%)	196 034	1860 (0.9%)
Lower GI	2393	422 (17.6%)	227 230	2369 (1.0%)
Major vessel	457	112 (24.5%)	19 330	819 (4.2%)
Male GU	126	19 (15.1%)	33 521	68 (0.2%)
Muscle	157	26 (16.6%)	56 427	84 (0.1%)
Nasal	181	36 (19.9%)	48 691	106 (0.2%)
Neurological	1675	436 (26.0%)	123 866	2654 (2.1%)
Obstetrics	2489	* (%*)	215 432	11 (0.0%)
Ocular	133	* (%*)	376 152	40 (0.0%)
Oral	130	19 (14.6%)	83 209	71 (0.1%)
Orthopaedics	30	* (%*)	13 823	11 (0.1%)
Other	395	111 (28.1%)	32 119	564 (1.8%)
Pharynx	45	9 (20.0%)	15 182	48 (0.3%)
Skin	1475	325 (22.0%)	233 798	1059 (0.5%)
Skull and spine	335	39 (11.6%)	62 216	279 (0.4%)
Thoracic	4722	1503 (31.8%)	20 185	1122 (5.6%)
Upper GI	999	258 (25.8%)	33 128	1228 (3.7%)
Urological	978	208 (21.3%)	165 758	816 (0.5%)
Vascular	1790	562 (31.4%)	65 040	1408 (2.2%)

Incidence of SARS-CoV-2 infection among surgical patients in Wales

We identified 116 531 patients undergoing their first surgical procedure in Wales between January 1, 2020 and February 28, 2021. In Wales, a higher proportion of patients underwent emergency surgery (29.4%) than in England (21.8%). Using ICD-10 codes alone, 1834/116 531 (1.5%) surgical patients in Wales had SARS-CoV-2 infection. Using SARS-CoV-2 polymerase chain reaction (PCR) tests resulted in a marginally decreased incidence of 1515/116 531 (1.3%). Using either ICD-10 code or SARS-CoV-2 PCR definitions, the incidence rose to 2182/116 531 (1.8%). Among elective surgical patients in Wales, SARS-CoV-2 infection ICD-10 codes were recorded amongst 166/72 262 (0.23%) patients. Adding positive SARS-CoV-2 PCR test results resulted in an increased incidence of 271/72 262 (0.38%) (Supplementary Table S7).

Post-hoc sensitivity analysis of emergency hospital readmission

A total of 2 587 789 patients were discharged alive before 30 days, and so eligible for hospital readmission. We identified 155 717 hospital readmissions within 30 days of surgery (6.1%), of which 6381 had a SARS-CoV-2 code recorded (0.2%). The rate of emergency hospital readmission with SARS-CoV-2 was 0.8% (4352/516 209) amongst patients who had emergency surgery, and 0.1% (1784/1 852 651) amongst patients undergoing elective surgery (Supplementary Table S8).

Discussion

The principal finding of this population-wide epidemiological study is that the incidence of SARS-CoV-2 infection among NHS surgical patients in England through 2020 and up to February 28, 2021 was 1.1%. Among those who were discharged, one in 405 were readmitted with SARS-CoV-2 within 30 days. Most hospital admissions with SARS-CoV-2 within 30 days of surgery were among patients who had emergency surgery. Where perioperative SARS-CoV-2 infection did occur, it was associated with more than a 5-fold increase in risk of in-hospital mortality. Meanwhile, the very low risk of in-hospital death (one in 1000) among patients undergoing elective surgery who have not been infected with SARS-CoV-2 suggests that infection prevention and control procedures to create COVID-19-free 'green' surgical pathways have been highly effective during the pandemic.[20,21] Surgical patients with symptomatic SARS-CoV-2 infection were five times more likely to die compared with infected patients without respiratory symptoms.

The incidence of SARS-CoV-2 infection requiring hospitalisation and subsequent deaths reported in this study represent the measured population incidences, rather than an estimate from a population sample. Our findings are consistent with previous estimates of perioperative mortality associated with SARS-CoV-2 infection.[22–27] The largest of these is the COVID-Surg international multicentre observational cohort study of 1128 surgical patients with confirmed SARS-CoV-2 infection, which was conducted during the first quarter of 2020.[8] It
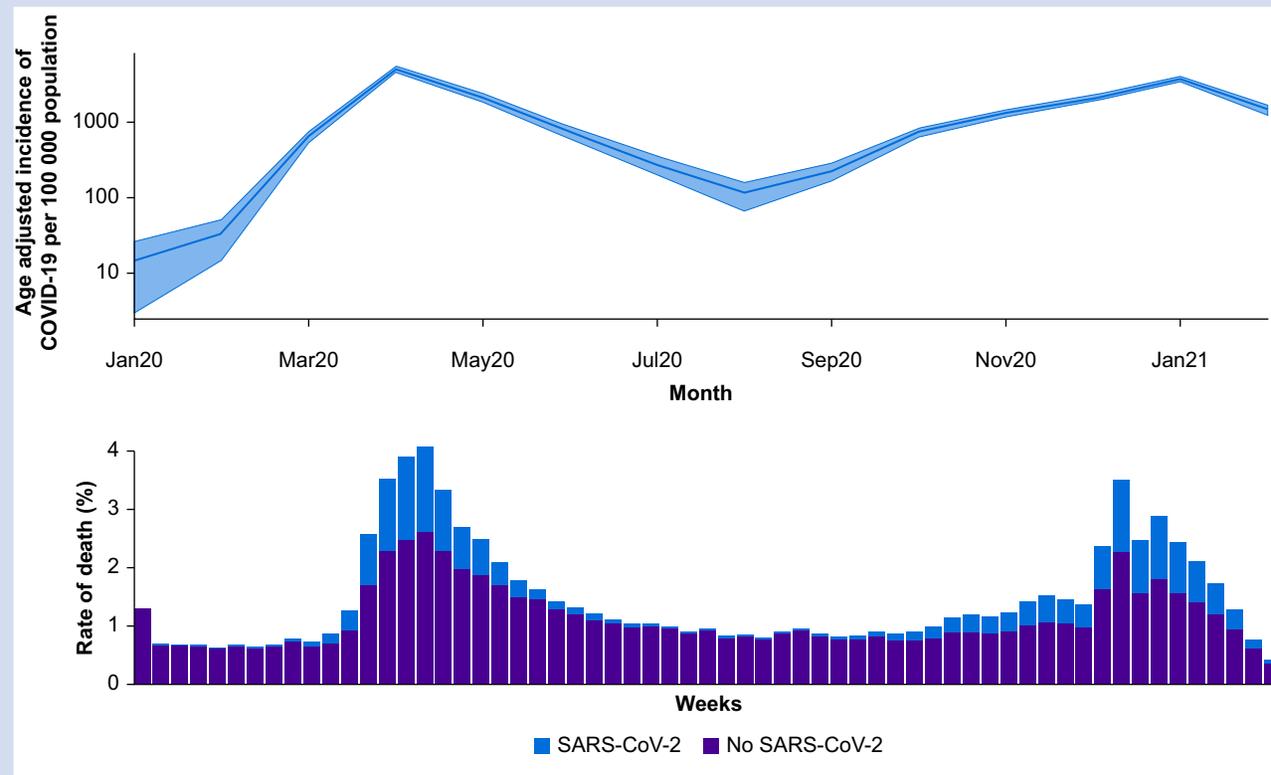
Fig 2. Top panel: age-adjusted incidence of SARS-CoV-2 infection amongst surgical patients, reported as the number of cases per 100 000 population (y axis on log scale). Bottom panel: weekly rate of death, stratified by SARS-CoV-2 infection status. SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

reported a 30-day mortality rate of 23.8%. However, the cohort consisted of only patients with confirmed SARS-CoV-2, so it was not possible to infer the relative risk of mortality associated with perioperative SARS-CoV-2 infection compared with a contemporaneous non-infected comparator. Our data contextualise these findings from early in the pandemic by reporting the population risk of mortality among surgical patients with SARS-CoV-2 in England using a cohort of patients

with SARS-CoV-2 infection that is more than 10 times larger. Because we included all patients undergoing surgery in England, we were able to compare the risk of mortality among patients with SARS-CoV-2 infection to patients without infection to provide an estimate of the relative risk of death associated with SARS-CoV-2 infection. This important finding, which until now was unknown, could inform shared decision-making about surgical care of patients with SARS-CoV-2.

Table 3 Mortality and hospital length of stay, stratified by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection status and acuity of surgery. Data are presented as median (inter-quartile range) or n (%).

	No SARS-CoV-2	SARS-CoV-2 infection			
		Any	Preoperative	Perioperative	Postoperative
All patients					
n	2 638 201	28 777	7418	18 484	2875
In-hospital death	20 211 (0.8%)	6153 (21.4%)	1544 (20.8%)	3755 (20.3%)	854 (29.7%)
Length of hospital stay (days)	0 (0—2)	13 (4—26)	9 (2—22)	12 (4—25)	23 (15—31)
Elective surgery					
n	1 857 586	2412	809	1456	147
In-hospital death	1414 (0.1%)	172 (7.1%)	21 (2.6%)	125 (8.6%)	26 (17.7%)
Length of hospital stay (days)	0 (0—1)	4 (1—16)	0 (0—3)	7 (2—20)	24 (14—33)
Emergency surgery					
n	559 374	22 918	5543	14 721	2654
In-hospital death	18 060 (3.2%)	5752 (25.1%)	1414 (25.5%)	3532 (24.0%)	806 (30.4%)
Length of hospital stay (days)	2 (1—7)	15 (6—28)	11 (4—24)	15 (6—28)	23 (15—31)

Table 4 Multivariable logistic regression analysis for in-hospital mortality within 90 days. Patients with unspecified sex removed before analysis. CI, confidence interval; GI, gastrointestinal; HPB, hepatopancreatobiliary; LGU, lower genitourinary; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; UGU, upper genitourinary.

	Odds ratio	Lower 95% CI	Upper 95% CI	P value
Intercept	<0.01	<0.01	<0.01	<0.001
SARS-CoV-2 code present	5.7	5.5	5.91	<0.001
Female compared with male	0.81	0.79	0.83	<0.001
Age (yr)	1.03	1.03	1.04	<0.001
Cancer present	1.04	1.01	1.08	0.01
Charlson Comorbidity Score: reference=0				
Score 1	2.41	2.3	2.54	<0.001
Score 2	3.72	3.53	3.92	<0.001
Score 3	5.01	4.74	5.3	<0.001
Score 4	6.17	5.8	6.56	<0.001
Score 5	7.07	6.57	7.61	<0.001
Score ≥6	7.71	7.09	8.38	<0.001
Index of Multiple Deprivation: reference=quintile 1 (most deprived)				
Quintile 2	0.99	0.95	1.03	0.55
Quintile 3	0.94	0.9	0.98	<0.001
Quintile 4	0.88	0.85	0.92	<0.001
Quintile 5 (least deprived)	0.88	0.84	0.91	<0.001
Missing quintile	1.17	1.03	1.33	0.016
Admission category: reference=elective				
Emergency	23.54	22.33	24.83	<0.001
Maternity	2.07	0.78	5.46	0.14
Other	16.59	15.2	18.08	<0.001
Procedure grouping: reference=bone				
Breast	0.23	0.14	0.38	<0.001
Cardiac	0.97	0.91	1.02	0.24
Cerebrovascular	2.67	2.31	3.09	<0.001
Ear	0.43	0.31	0.59	<0.001
Endocrine	1.32	0.94	1.86	0.107
Female LGU	0.51	0.34	0.79	0.002
Female UGU	0.37	0.28	0.49	<0.001
HPB	1.53	1.41	1.67	<0.001
Joint	1.05	0.99	1.12	0.077
Lower GI	1.73	1.63	1.83	<0.001
Major vessel	2.72	2.5	2.96	<0.001
Male GU	0.69	0.55	0.87	0.001
Muscle	0.81	0.66	0.99	0.035
Nasal	0.46	0.38	0.54	<0.001
Neuro	3.46	3.26	3.66	<0.001
Obstetrics	0.31	0.12	0.77	0.012
Ocular	0.09	0.06	0.11	<0.001
Oral	0.63	0.51	0.78	<0.001
Orthopaedics	0.43	0.25	0.74	0.003
Other	2.52	2.3	2.77	<0.001
Pharynx	1.71	1.3	2.26	<0.001
Skin	0.83	0.77	0.89	<0.001
Skull and spine	1.38	1.22	1.56	<0.001
Thoracic	5.07	4.75	5.41	<0.001
Upper GI	3.3	3.08	3.54	<0.001
Urological	0.89	0.83	0.97	0.004
Vascular	1.85	1.74	1.98	<0.001

The volume of surgical activity during the pandemic was greatly reduced for three main reasons.[4–6,28,29] First, the reduced capacity for elective surgery as a result of reallocation of staff and resources to the care of hospitalised patients with COVID-19 pneumonia.[30] Second, the reorganisation of care pathways and the introduction of necessary, but onerous, infection control procedures have slowed down the delivery of care and patient throughput.[21,31] Third, the reluctance of some clinicians to operate on patients at high risk of complications should they suffer a nosocomial infection with SARS-CoV-2.[5,32] This is coupled with a reluctance of some patients to undergo surgery because of fears of acquiring SARS-CoV-2 in hospital at the time of surgery. Measures to prevent nosocomial infection include preoperative testing, household isolation, and dedicated 'green' pathways for patients who are known to be SARS-CoV-2 negative. Patients and clinicians should be reassured that the population incidence of SARS-CoV-2 among surgical patients is low, and the overall risk of death from SARS-CoV-2 for a patient undergoing elective surgery in a 'green' pathway is less than 1 in 11 000.[20] Our data confirm that the volume of surgical activity during 2020 is about 25% lower than expected compared with previous years.[1,2] The predicted delays to surgical treatments as a result of the pandemic are substantial, with an estimated 5 million cases outstanding by March 2021.[4] Although the morbidity and mortality associated with cancelled or postponed surgery is unknown, it is clearly not desirable to have a large and rapidly expanding waiting list for treatments.[5,31] Our data confirm that although it is possible to undertake surgery safely during the pandemic, the risk of mortality among surgical patients with SARS-CoV-2 is substantial, and all efforts should be made to prevent nosocomial infection.

This study has several strengths. We included data from all patients undergoing surgery in England during the COVID-19 pandemic in England; thus our results represent the true population incidence of SARS-CoV-2 infection and associated mortality. We included data from more than 2 million surgical patients, which represents one of the largest observational cohorts of surgical patients during the COVID-19 pandemic. These data will be generalisable to other high-income countries. A major strength of our analysis is that we controlled for changing surgical case mix during the pandemic, and potential factors that could confound association between SARS-CoV-2 infection and mortality. We used the contemporaneous comparator of patients undergoing surgery during the pandemic who did not have SARS-CoV-2 infection. This allowed us to control for unexpected changes in surgical case mix associated with changes in population behaviour and healthcare delivery. We explored the potential for misclassification of SARS-CoV-2 status using a sample of patients from Wales with detailed SARS-CoV-2 testing data. The incidence of SARS-CoV-2 defined using ICD-10 codes in this cohort was higher than that in England, possibly because of a higher proportion of emergency surgical patients. The paradoxically lower incidence of SARS-CoV-2 recorded on PCR tests is likely attributable to the reduced availability of tests during the first wave, where clinical suspicion was required for diagnosis. Adding SARS-CoV-2 PCR tests increased the incidence compared with ICD-10 codes alone by about 15%. However, among elective surgical patients, the incidence of SARS-CoV-2 infection remained very low (<0.4%).

Our analysis also has several limitations. It possible that our data underestimate the true incidence of SARS-CoV-2 infection among surgical patients, particularly amongst those undergoing day case procedures, which would lead to under-representation of asymptomatic patients who are less likely to die. We determined the proportion of patients requiring emergency hospital admission with SARS-CoV-2
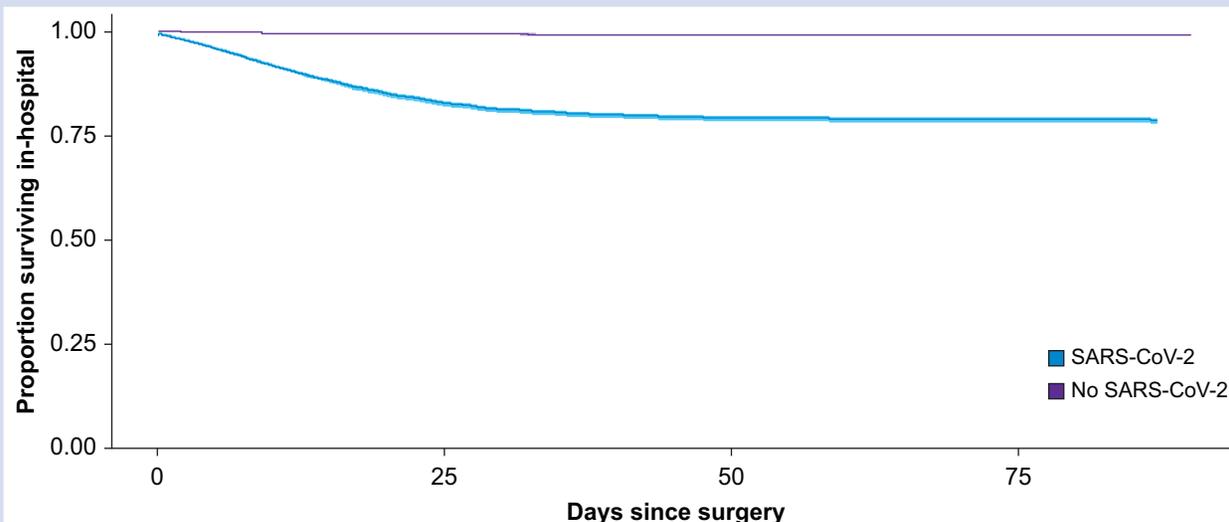
Fig 3. Kaplan—Meier survival curves stratified by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2 status).

within 30 days of surgery in England and found this was very low, particularly among elective surgical patients. We only included in-hospital deaths, and our findings will therefore underestimate the true mortality risk. Early in the pandemic, testing may have only been available to patients with more severe disease leading to an over-representation of these cases. SARS-CoV-2 may cause asymptomatic disease, and our case definition would miss these patients. Our sensitivity analysis indicates that ICD-10 codes under-report SARS-CoV-2 infections by about 15% compared with SARS-CoV-2 PCR results. However, the overall incidence of SARS-CoV-2 infection remained low, particularly amongst elective surgical patients. Administrative data sets are dependent on coding quality. Data are coded by trained professionals according to standardised methods.[33–35] Reports indicate HES are accurate, particularly for procedures and important diagnoses. The influence of the pandemic on coding quality is unclear, but our sensitivity analysis results suggest that the quality of SARS-CoV-2 coding is good. At the date of our data extract, some patients will have remained in hospital so the true impact of the second wave will not be fully captured.

In conclusion, we have shown that the prevalence of SARS-CoV-2 infection among surgical patients is low and the risk of postoperative mortality among patients without SARS-CoV-2 infection is very small. However, where it occurs, SARS-CoV-2 infection among surgical patients is associated with a very high risk of death.

Authors' contributions

Study design: TA, AF, TD, RP
Data collection: AF, GD, AA
Data analysis: AF, TA, JG
Data interpretation: AF, TD, RP, TA
Writing of the first draft of the manuscript: TA, RP
All authors revised the manuscript for important intellectual content and approved the final version. AJF and TA had full access to the data and act as guarantors.

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Declarations of interest

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Transparency declaration

TA affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

Dissemination declaration

The results of this study have been shared with representatives from NHS England before publication, in order to inform patient care.

Patient and public involvement

A patient representative was consulted in the design of this study.

Funding

Data sharing

The data used in this study were derived from two data sources. It is not possible to share the raw patient-level data provided by NHS Digital describing NHS patients in England. Regarding data from NHS patients in Wales, the data used are available in the SAIL Databank at Swansea University, Swansea, UK, but as restrictions apply they are not publicly available. All proposals to use SAIL data are subject to review by an independent Information Governance Review Panel (IGRP). Before any data can be accessed, approval must be given by the IGRP. The IGRP gives careful consideration to each project to ensure proper and appropriate use of SAIL data. When access has been granted, it is gained through a privacy protecting safe haven and remote access system referred to as the SAIL Gateway. SAIL has established an application process to be followed by anyone who would like to access data via SAIL at https://www.saildatabank.com/application-process.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2021.05.018.

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