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Preoperative nasopharyngeal swab testing and postoperative pulmonary complications in patients undergoing elective surgery during the SARS-CoV-2 pandemic

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Abstract

Introduction: Surgical services are preparing to scale-up in areas affected by COVID-19. This study aimed to evaluate the association between preoperative SARS-CoV-2 testing and postoperative pulmonary complications in patients undergoing elective cancer surgery.

Methods: International cohort study including adult patients undergoing elective surgery for cancer in areas affected by SARS-CoV-2 up to 19 April 2020 (NCT04384926). Patients suspected of SARS-CoV-2 infection preoperatively were excluded. The primary outcome measure was postoperative pulmonary complications at 30 days after surgery. Preoperative testing strategies were adjusted for confounding using mixed-effects models.

Results: Of 8784 patients (432 hospitals, 53 countries), 2303 patients (26.2%) underwent preoperative testing: 1458 (16.6%) had a swab test, 521 (5.9%) CT only, and 324 (3.7%) swab and CT. Pulmonary complications occurred in 3.9% while SARS-CoV-2 infection was confirmed in 2.6%. After risk adjustment, having at least one negative preoperative nasopharyngeal swab test (adjusted odds ratio 0.68, 95% confidence interval 0.68-0.98, $p=0.040$) was associated with a lower rate of pulmonary complications. Swab testing was beneficial before major surgery and in areas with a high 14-day SARS-CoV-2 case notification rate but not before minor surgery or in low risk areas. To prevent one pulmonary complication in major or minor surgery the respective number needed to swab test was 18 and 48 in high, and 73 and 387 in low risk areas.

Discussion: Preoperative nasopharyngeal swab testing was beneficial before major surgery and in high SARS-CoV-2 risk areas. There was no proven benefit of swab testing before minor surgery in low risk areas.

Introduction

Globally, at least 28 million elective operations have been cancelled as a result of the first SARS-CoV-2 pandemic wave.¹ During the initial phases, operations in affected hospitals were identified as carrying significant risk, with perioperative SARS-CoV-2 infection leading to a far higher rate of pulmonary complications than before the pandemic.² Once established, a SARS-CoV-2 postoperative pulmonary complication was associated with a 23.8% mortality rate, compared to a 2% mortality rate without SARS-CoV-2.³ Because of this, re-starting elective surgery has proved challenging, with many millions more operations being postponed every month.

Healthcare providers have continued some time-dependent surgery (e.g. for cancer) and are gearing up to provide other essential types of elective surgery. The role of preoperative testing for SARS-CoV-2 in these surgical pathways is unproven. On one hand, it has the potential to optimise outcomes by identifying pre-symptomatic patients with SARS-CoV-2 infection for whom surgery can be postponed. On the other, there is a time and cost burden of testing, with uncertainty around the best strategy and variable global availability.⁴⁻⁶ The mainstay of testing is nasopharyngeal swab test with quantitative reverse transcription PCR (RT-qPCR) to detect SARS-CoV-2 viral RNA,^{7,8} although preoperative computed tomography has also been suggested, especially before major surgery.⁹

To support the global implementation of testing before elective surgery, better evidence is needed to support its role and to identify patients that will benefit most. This includes the role of routine testing before major and minor surgery, and in high and low SARS-CoV-2 risk areas. Elective cancer surgery performed during the early pandemic allows us to assess the performance of preoperative testing, and acts as a surrogate for other elective operations. This study aimed to evaluate the association between preoperative testing and postoperative

pulmonary complications in patients undergoing elective cancer surgery in areas affected by the SARS-CoV-2 pandemic.

Methods

Study design and protocol

This was an international multi-centre cohort study of adults undergoing elective cancer surgery in areas affected by the SARS-CoV-2 pandemic that were not suspected of SARS-CoV-2 infection before surgery. Local investigators were responsible for obtaining local approvals in line with applicable regulations. Data were collected online and stored on a secure data server running the Research Electronic Data Capture (REDCap) web application.¹⁰ The study protocol was registered on ClinicalTrials.gov (NCT04384926) and has been previously reported in detail.¹¹

Patients and procedures

Adult patients (18 years and over) undergoing elective surgery with curative intent for a suspected cancer were included. Centres were required to include consecutive patients undergoing surgery for an eligible cancer type. Ten common surgical oncology disciplines were included spanning colorectal, oesophagogastric, head and neck, thoracic, hepatopancreatobiliary, urological, gynaecological, breast, sarcoma and intracranial tumours. Participating centres were allowed to include one or more cancer types. Eligible patients were identified from multidisciplinary team meeting lists, operating lists, outpatient clinics and inpatient wards. Patients were followed up to 30 days from the day of surgery (day zero).

Patients who had symptoms of COVID-19 or who were confirmed to have SARS-CoV-2 infection at the time of surgery (by qRT-PCR and/or imaging by computed tomography (CT) thorax in the 7 days before surgery) were excluded from this study. This study therefore included only patients who were not suspected of SARS-CoV-2 at the time of surgery. Data were not collected on patients that were identified as being SARS-CoV-2 positive and for whom surgery was postponed.

Centres and settings

Any hospital performing elective cancer surgery during the SARS-CoV-2 pandemic was eligible to participate. Centres enrolled consecutive patients from the date the first SARS-CoV-2 infected patient was admitted to their hospital up to 19 April 2020.

Preoperative testing strategies

Preoperative testing was defined as any test used for the identification of a patient's SARS-CoV-2 status in the 7 days before surgery. Four preoperative testing strategies were defined in this analysis: (1) Swab test, defined as nasopharyngeal swab and identification of viral RNA by RT-qPCR, according to local protocols; (2) Imaging by computed tomography (CT) thorax only; (3) Swab test and CT; (4) No test. Timing of swab testing was categorised as: (1) single swab test at day 4 to 7 preoperatively; (2) single swab test at day 1 to 3 preoperatively; (3) repeat swab, defined as one or more swabs on day 1 to 3 and day 4 to 7 preoperatively.

Outcome measures

The primary outcome measure was the rate of postoperative pulmonary complications within 30 days after surgery. This included pneumonia, acute respiratory distress syndrome (ARDS), and/or unexpected postoperative ventilation. The secondary outcome measures were postoperative SARS-CoV-2 infection and mortality within 30 days after surgery. Postoperative SARS-CoV-2 infection was defined as a positive swab test, CT thorax, or clinical diagnosis of symptomatic COVID-19 in patients for whom a swab test and CT scan were unavailable.

Variables used in patient-level risk adjustment

Clinically plausible variables likely to be associated with the primary outcome measure were collected to allow risk adjustment. A patients' health and functional status preoperatively was

summarised using age, sex, body mass index, respiratory condition, revised cardiac risk index, and American Society of Anaesthesiologist grade. The body cavity accessed during surgery was classified as thoracic or thoracoabdominal, abdominal or other. To account for different tumour staging systems across cancer types, disease status was classified as early (organ confined, non-nodal, non-metastatic, fully resectable) or advanced stage (growth beyond organ, nodal, metastatic operated with curative intent). Grade of surgery was categorised based on the Clinical Coding & Schedule Development Group as either Minor (minor/intermediate) or Major (major/complex major).¹² The community SARS-CoV-2 14-day case notification rate at the time of surgery within each participating hospital's local community was extracted from the World Health Organisation¹³, European Centre for Disease Prevention and Control¹⁴, or US Centre for Disease Control and Prevention (CDC) statistics. Hospitals were classified as being in communities with either low (<25 cases per 100,000 population) or high (≥25 cases per 100,000 population) SARS-CoV-2 risk. Each patient was classified as undergoing surgery within a COVID-19 free surgical pathway or with no defined pathway.¹¹ Patients were classified as being treated within a COVID-19 free pathway if there was a policy of complete segregation from COVID-19 patients away from the operating room, critical care, and inpatient ward.

Data validation

Studies adopting this collaborative cohort study methodology have achieved high levels of case ascertainment and data accuracy with external validation.^{15,16} In this study, low volume centres (less than 5 patients per specialty group) were identified, and independently reviewed to confirm complete case ascertainment. Where specialty teams could not confirm complete case ascertainment, all data were excluded from analysis.

Statistical analysis

The study was conducted according to STROBE¹⁷ (Strengthening the Reporting of Observational Studies in Epidemiology) and reported according to SAMPL¹⁸ (Statistical Analyses and Methods in the Published Literature). Missing data were described and included in summary tables where applicable. Non-parametric data were summarised with medians and interquartile ranges and differences between groups were tested using the Mann-Whitney U test. The χ^2 test was used for categorical data.

Hierarchical, multi-level univariable and multivariable logistic regression models were used to examine associations between preoperative testing strategy and the primary outcome measure, summarised as adjusted odds ratios (OR) with 95% confidence intervals (C.I.). Clinically plausible patient, disease, operation and location specific factors were selected *a priori* for inclusion in adjusted analyses in order to identify independent predictors of postoperative pulmonary complications (primary outcome). Country was included as a random effect in the adjusted models. Number needed to test (NNT) was calculated as $1/ARR$, where ARR is the adjusted absolute risk reduction. NNT is interpreted as the number of subjects that need to be tested in order to prevent an additional pulmonary complication. Analyses were carried out using the R Foundation Statistical Program version 3.1.1 (packages: finalfit, tidyverse, ggplot2).

Subgroup analyses

As the mainstay of current testing protocols, we predicted that the most common preoperative test would be nasopharyngeal swab test. We pre-planned to explore the impact of swab tests on two key subgroups: firstly, high versus low SARS-CoV-2 risk and secondly, major versus minor operations.

Data sharing

Data sharing requests will be considered by the management group upon written request to the corresponding author. If agreed, de-identified participant data will be available subject to a Data Sharing Agreement.

Results

Of 9171 patients included in this study, 8784 (95.8%) had data available on preoperative testing and were included in this analysis. Operations were performed in 432 hospitals from 53 countries, of which 6746 (76.7%) were major and 1087 (12.4%) were performed in high SARS-CoV-2 risk areas. A full list of included operations grouped by preoperative testing strategy is presented in *Supplementary Table 1*.

Preoperative testing strategies

Overall, 26.4% of patients (2303/8734) underwent preoperative testing. This included 1458 (16.6%) with a swab test, 521 (5.9%) with CT only, and 324 (3.7%) with swab and CT. There was significant variation in the proportion of patients that underwent testing at country level (*Figure 1*). The overall proportion of patients that were tested increased over the study period (*Supplementary Figure 1*).

There were several differences between groups with different preoperative testing strategies. Patients undergoing testing were more likely to have surgery in a high SARS-CoV-2 risk area and be treated within a COVID-19 free surgical pathway (*Table 1*). In general, higher risk patients (for example those undergoing major surgery, general anaesthesia, or of higher performance score) were more likely to have a swab test than no test. Of patients undergoing swab testing (n=1458), 164 (11.2%) on preoperative day 4 to 7, 1213 (83.2%) had a single swab on preoperative day 1 to 3, and just 63 (4.3%) had repeat swabs. The groups undergoing CT either alone or with a swab test more commonly underwent thoracic or thoracoabdominal surgery, or had an advanced disease stage.

Pulmonary complications

The overall postoperative pulmonary complication rate was 3.9% (346/8784). This was higher in patients with no testing (4.2%, 272/6481) or CT only (4.8%, 25/521) than with swab test (2.8%, 41/1458) or swab and CT (2.5%, 8/324; $p < 0.001$). After adjustment, a swab test was associated with reduced pulmonary complications (adjusted OR: 0.68, 95% C.I. 0.47 to 0.98, $p = 0.040$); a CT only, or swab and CT were not (*Figure 2*). There was no additional benefit observed by repeat swab testing beyond a single swab at preoperative day 1 to 3 (*Table 2*).

Subgroup analyses

Swab testing was associated with a reduction in pulmonary complications in high risk areas (adjusted OR: 0.25, 95% C.I. 0.09 to 0.76, $p = 0.014$, *Supplementary Table 3*) but not in low risk areas (adjusted OR: 0.72, 95% C.I. 0.48 to 1.08, $p = 0.108$, *Supplementary Table 4*). Swab testing was associated with a reduction in pulmonary complications after major surgery (adjusted OR: 0.63, 95% C.I. 0.42 to 0.93, $p = 0.019$, *Supplementary Table 5*) but not after minor surgery (adjusted OR: 0.58, 95% C.I. 0.16 to 2.13, $p = 0.413$, *Supplementary Table 6*). A summary of subgroup models is displayed in *Figure 3*.

The number needed to test (NNT) to prevent one postoperative pulmonary complication across subgroups is shown in *Table 3*. This reduced across major (NNT=18) and minor (NNT=48) surgery in high risk areas, and major (NNT=73) and minor (NNT=387) surgery in low risk areas.

Postoperative detection of SARS-CoV-2 and mortality

SARS-CoV-2 infection and mortality rates by preoperative testing strategy is reported in *Table 4*. The unadjusted rate of SARS-CoV-2 detected postoperatively was lower in all groups that were tested preoperatively when compared to those with no testing ($p < 0.001$). The difference was greatest between swab test (0.5%, 7/1458) versus no test (3.2%, 209/6481). Mortality was lower in the group undergoing swab tests (0.8%, 12/1458) or swab test and CT (0.6%, 5/324)

than those with no testing (1.6%, 104/6841), although this was not statistically significant ($p=0.072$).

Discussion

This study demonstrated that a preoperative nasopharyngeal swab test with RT-qPCR to detect SARS-CoV-2 in asymptomatic patients was associated with a reduced rate of postoperative pulmonary complications. The main benefit was seen in major surgery and in areas with a high 14-day case notification rate. No clear benefit was seen in minor surgery performed in low risk areas. There was no benefit seen with the addition of preoperative CT thorax or repeat swabs. This allows us to make practice changing recommendations. A single preoperative swab should be performed for patients with no clinical suspicion of COVID-19 before major surgery in both high and low risk areas and before minor surgery in high risk population areas. The numbers needed to test presented for these groups provide evidence to support implementation by healthcare providers, based on locally available resources.

The beneficial association seen with swab testing was likely to be due to identification of pre-symptomatic or asymptomatic patients prior to their admission, who could then have their operation delayed. This effect is mediated by two mechanisms. Firstly, it stops pre-symptomatic patients developing severe, symptomatic disease (i.e. COVID-19) after their operation. Secondly, it prevents cross-infection from asymptomatic patients to other elective surgical patients upon admission to hospital. To reinforce these benefits, preoperative swab testing should not be considered in isolation, but as part of a broader strategy to reduce SARS-CoV-2 exposure, including dedicated COVID-19 free surgical pathways.¹¹

This study did not aim to evaluate the diagnostic accuracy of swab testing, which has been explored in detail elsewhere.^{7,8,19,20} Whilst we did not see a clear benefit to repeat swabs in this data, there were only a small group who received two or more tests. There is a documented false negative rate of RT-qPCR from a nasopharyngeal swab test, with an estimated sensitivity of 73.3% (95% C.I. 68.1%-78.0%).²⁰ For patients identified at highest baseline risk of pulmonary

complications and/or SARS-CoV-2 infection, for example older patients, worse functional status, or undergoing thoracoabdominal surgery, there may still be a role for selective repeat swabbing. As understanding of the diagnostic accuracy of SARS-CoV-2 tests evolve over time, new testing strategies (e.g. serology) may be integrated into this pathway.

This study demonstrated major country-by-country variation in the application of preoperative testing. The results call for global expansion and standardisation of swab testing worldwide. The reasons for this variation need better understanding, including relationships to health system resourcing and policy^{4,5}. In our data, the testing rate increased over time from less than 10% at the end of February, to almost 40% in the middle of April 2020. Whilst this indicates a growing uptake of preoperative swab testing internationally, implementation remained incomplete with 18 countries reporting a 0% testing rate. Care providers should now upscale the provision of routine preoperative testing to provide safe elective surgery during the pandemic.

CT scanning remains controversial as it is resource intensive to perform and its validity in detection of COVID-19 has not been demonstrated, despite proposed scoring systems²¹⁻²³. Furthermore, a systematic review of diagnostic accuracy studies has failed to demonstrate the accuracy of CT thorax as a screening tool in asymptomatic patients²³. In our study, CT was used more commonly in groups undergoing thoracoabdominal surgery and those with advanced disease stage. There may be a selected role in a dual-purpose scan before surgery that can both restage disease after a delay to surgery, and identify characteristic changes of COVID-19. We found no additional benefit to performing CT in addition to a single swab test, meaning additional cost and organisational burden of CT as a screening test in asymptomatic patients is unlikely to be justified. This corroborates findings of a multi-centre study of 2093 patients undergoing surgery in the Netherlands, in which the incremental yield of CT thorax in asymptomatic patients was slight, at 0.4%.^{9,22} Similarly, in a small French series, high-

resolution CT chest added very little additional value and a high resource cost, with just 3 of 386 swab negative patients undergoing CT thorax having surgery postponed.²²

There were limitations to this study. Firstly, its observational nature may have left a residual risk of selection bias, despite statistical techniques to take this into account. However, patients undergoing preoperative testing were at higher, rather than lower, risk of pulmonary complications at baseline, so this is unlikely to have affected the effect observed. Secondly, some of the subgroup sizes were small (e.g. CT scanning, repeat swabs), meaning there were risks of type II errors. Thirdly, cancer surgery was used in this study as a surrogate for elective operations, and its findings could be extrapolated to other types of elective surgery in order to support re-starts and upscaling. In some cases, this may need to be done with caution, due to differences in operation and patient profiles. Finally, this study was designed as a pragmatic, real-world analysis of the effectiveness of testing in patients that were not suspected of COVID-19 prior to elective surgery. We did not design it to test the diagnostic accuracy of different testing protocols.

The strengths of this study are in the large number of patients, a pan-surgical oncology approach, and multinational nature, which provide a route for future research. The role of preoperative isolation in combination with negative swab findings needs urgent assessment, as this is highly burdensome for patients and organisationally challenging. Urgent research is also needed to identify the optimum delay to surgery for patients who have a positive swab test. We did not analyse symptom questionnaires or clinical assessment as a method of identifying SARS-CoV-2 infected patients. Although these may prove effective in identifying some subtly symptomatic patients, they are currently not standardised and thus reproducibility is uncertain.

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Table 1. Comparison of patients by type of preoperative testing

Factor	Levels	None (n=6481)	Swab only (n=1458)	CT only (n=521)	Swab + CT (n=324)	P-value
Age, n (%)	<50 years	1212 (18.7)	227 (15.6)	95 (18.2)	52 (16.0)	0.069
	50-59 years	1393 (21.5)	296 (20.3)	120 (23.0)	84 (25.9)	
	60-69 years	1786 (27.6)	413 (28.3)	140 (26.9)	93 (28.7)	
	70-79 years	1571 (24.2)	381 (26.1)	128 (24.6)	73 (22.5)	
	≥80 years	519 (8.0)	141 (9.7)	38 (7.3)	22 (6.8)	
Sex, n (%)	Female	4000 (61.7)	844 (57.9)	320 (61.4)	195 (60.2)	0.056
	Male	2479 (38.3)	614 (42.1)	201 (38.6)	129 (39.8)	
	(Missing)	2	0	0	0	
Body Mass Index, n (%)	Normal	2406 (37.1)	665 (45.6)	227 (43.6)	114 (35.2)	<0.001
	Overweight	1974 (30.5)	467 (32.0)	184 (35.3)	123 (38.0)	
	Obese	1421 (21.9)	262 (18.0)	83 (15.9)	75 (23.1)	
	Underweight	149 (2.3)	38 (2.6)	15 (2.9)	9 (2.8)	
	Missing	531 (8.2)	26 (1.8)	12 (2.3)	3 (0.9)	
ASA Grade, n (%)	ASA grade 1-2	4655 (72.2)	999 (68.5)	412 (79.2)	257 (79.3)	<0.001
	ASA grade 3-5	1792 (27.8)	459 (31.5)	108 (20.8)	67 (20.7)	
	(Missing)	34	0	1	0	
Revised Cardiac Risk Index, n (%)	0	2147 (33.1)	482 (33.1)	125 (24.0)	43 (13.3)	<0.001
	1	3175 (49.0)	727 (49.9)	301 (57.8)	220 (67.9)	
	2	923 (14.2)	212 (14.5)	81 (15.5)	49 (15.1)	
	≥3	236 (3.6)	37 (2.5)	14 (2.7)	12 (3.7)	
	(Missing)	0	0	0	0	
Respiratory comorbidity, n (%)	No	5771 (89.0)	1302 (89.3)	469 (90.0)	289 (89.2)	0.915
	Yes	710 (11.0)	156 (10.7)	52 (10.0)	35 (10.8)	
ECOG Performance Score, n (%)	0	4115 (64.7)	842 (58.1)	338 (64.9)	220 (67.9)	<0.001
	≥1	2247 (35.3)	606 (41.9)	183 (35.1)	104 (32.1)	
	(Missing)	119	10	0	0	
Cancer type, n (%)	Abdominal	3430 (52.9)	784 (53.8)	327 (62.8)	238 (73.5)	<0.001
	Thoracic or thoracoabdominal	471 (7.3)	79 (5.4)	44 (8.4)	38 (11.7)	
	Other	2580 (39.8)	595 (40.8)	150 (28.8)	48 (14.8)	
Disease stage, n (%)	Early stage	4664 (72.0)	1029 (70.6)	356 (68.3)	193 (59.8)	<0.001
	Advanced stage	1814 (28.0)	429 (29.4)	165 (31.7)	130 (40.2)	
	(Missing)	3	0	0	1	
Anaesthetic, n (%)	General anaesthetic	6137 (94.7)	1365 (93.6)	510 (97.9)	316 (97.5)	<0.001
	Regional/local anaesthetic	344 (5.3)	93 (6.4)	11 (2.1)	8 (2.5)	
Operation grade, n (%)	Minor	1529 (23.7)	349 (24.0)	90 (17.3)	37 (11.4)	<0.001
	Major	4921 (76.3)	1107 (76.0)	431 (82.7)	287 (88.6)	
	(Missing)	31	2	0	0	
Hospital type, n (%)	No defined pathway	5033 (77.7)	1070 (73.4)	217 (41.7)	120 (37.0)	<0.001
	COVID-19 free surgical pathway	1447 (22.3)	388 (26.6)	304 (58.3)	204 (63.0)	
Community SARS-Cov-2 risk, n (%)	Low	5907 (91.1)	1258 (86.3)	331 (63.5)	201 (62.0)	<0.001
	Moderate or high	574 (8.9)	200 (13.7)	190 (36.5)	123 (38.0)	

CT=Imaging by computed tomography (CT) thorax. ASA=American Society of Anaesthesiologists. ECOG=Eastern Cooperative Oncology Group. Percentages calculated as a proportion of column total. P-values calculated using X² test.

Table 2. Association of timing and number of preoperative swab tests and postoperative pulmonary complications.

Factor	Level	Unadjusted model (Odds ratio, 95% CI)	Adjusted model (Odds ratio, 95% CI)	P-value
Screening type	None	-	-	-
	1 swab (4-7 days preoperatively)	0.36 (0.11 to 1.13)	0.33 (0.10 to 1.08)	0.067
	1 swab (1-3 days preoperatively)	0.65 (0.46 to 0.91)	0.66 (0.46 to 0.94)	0.023
	Repeat swabs ^a	0.30 (0.04 to 2.15)	0.34 (0.05 to 2.50)	0.288
Age	<50 years	-	-	-
	50-59 years	1.77 (0.97 to 3.24)	1.24 (0.67 to 2.29)	0.498
	60-69 years	3.50 (2.04 to 6.00)	1.79 (1.02 to 3.14)	0.042
	70-79 years	4.84 (2.84 to 8.24)	1.93 (1.10 to 3.40)	0.023
	≥80 years	4.81 (2.65 to 8.73)	1.84 (0.97 to 3.51)	0.064
Sex	Female	-	-	-
	Male	3.41 (2.63 to 4.42)	2.15 (1.63 to 2.83)	<0.001
Body Mass Index	Normal	-	-	-
	Overweight	1.06 (0.78 to 1.45)	0.88 (0.64 to 1.22)	0.445
	Obese	1.23 (0.89 to 1.71)	0.92 (0.65 to 1.31)	0.652
	Underweight	1.22 (0.55 to 2.67)	1.12 (0.50 to 2.53)	0.786
	Missing	1.75 (1.15 to 2.64)	1.63 (1.05 to 2.53)	0.030
ASA Grade	Grade 1-2	-	-	-
	Grade 3-5	2.61 (2.05 to 3.33)	1.27 (0.96 to 1.70)	0.097
Specialty	Abdominal	-	-	-
	Thoracic or thoracoabdominal	3.05 (2.23 to 4.18)	2.62 (1.86 to 3.69)	<0.001
	Other	0.33 (0.23 to 0.46)	1.13 (0.65 to 1.97)	0.674
ECOG Performance Score	0	-	-	-
	≥1	2.99 (2.33 to 3.85)	1.87 (1.40 to 2.49)	<0.001
Current smoker	No	-	-	-
	Yes	1.68 (0.23 to 2.58)	1.34 (0.94 to 1.91)	0.108
Pre-existing respiratory condition	No	-	-	-
	Yes	2.20 (1.62 to 2.98)	1.29 (0.92 to 1.80)	0.138
Revised Cardiac Risk Index	0	-	-	-
	1	4.18 (2.73 to 6.40)	1.97 (1.02 to 3.78)	0.042
	2	6.10 (3.82 to 9.74)	2.05 (1.00 to 4.18)	0.050
	≥3	10.83 (6.16 to 19.02)	2.86 (1.27 to 6.42)	0.011
Operation grade	Minor	-	-	-
	Major	4.22 (2.66 to 6.67)	2.23 (1.33 to 3.74)	0.002
Disease stage	Early stage	-	-	-
	Advanced stage	2.15 (1.69 to 2.75)	1.74 (1.35 to 2.25)	<0.001
Hospital type	No defined pathway	-	-	-
	COVID-19 free surgical pathway	0.40 (0.26 to 0.59)	0.55 (0.36 to 0.84)	0.006
Community SARS-Cov-2 risk	Low	-	-	-
	Moderate or high	1.43 (1.01 to 2.02)	1.54 (1.06 to 2.22)	0.023

Data included from 6217 patients with complete data. CT=Imaging by computed tomography (CT) thorax. ^aRepeat swab=One or more swabs on day 1 to 3 and day 4 to 7 preoperatively. ASA=American Society of Anaesthesiologists. ECOG=Eastern Cooperative Oncology Group. Percentages calculated as a proportion of row total. Area under the Receiver Operating Characteristic curve for model: 0.80 (excellent discrimination).

Table 3. Number needed to test to prevent one postoperative pulmonary complication through preoperative SARS-CoV-2 swab testing.

	No test	Swab test	Adjusted ARR	NNT
Major surgery, high risk area	7.7% 33/429	3.7% 5/134	5.67%	18
Minor surgery, high risk area	2.1% 3/144	0.0% 0/66	2.10% ^a	48
Major surgery, low risk area	4.9% 219/4492	3.4% 33/973	1.37%	73
Minor surgery, low risk area	1.2% 16/1385	1.1% 3/283	0.26%	387

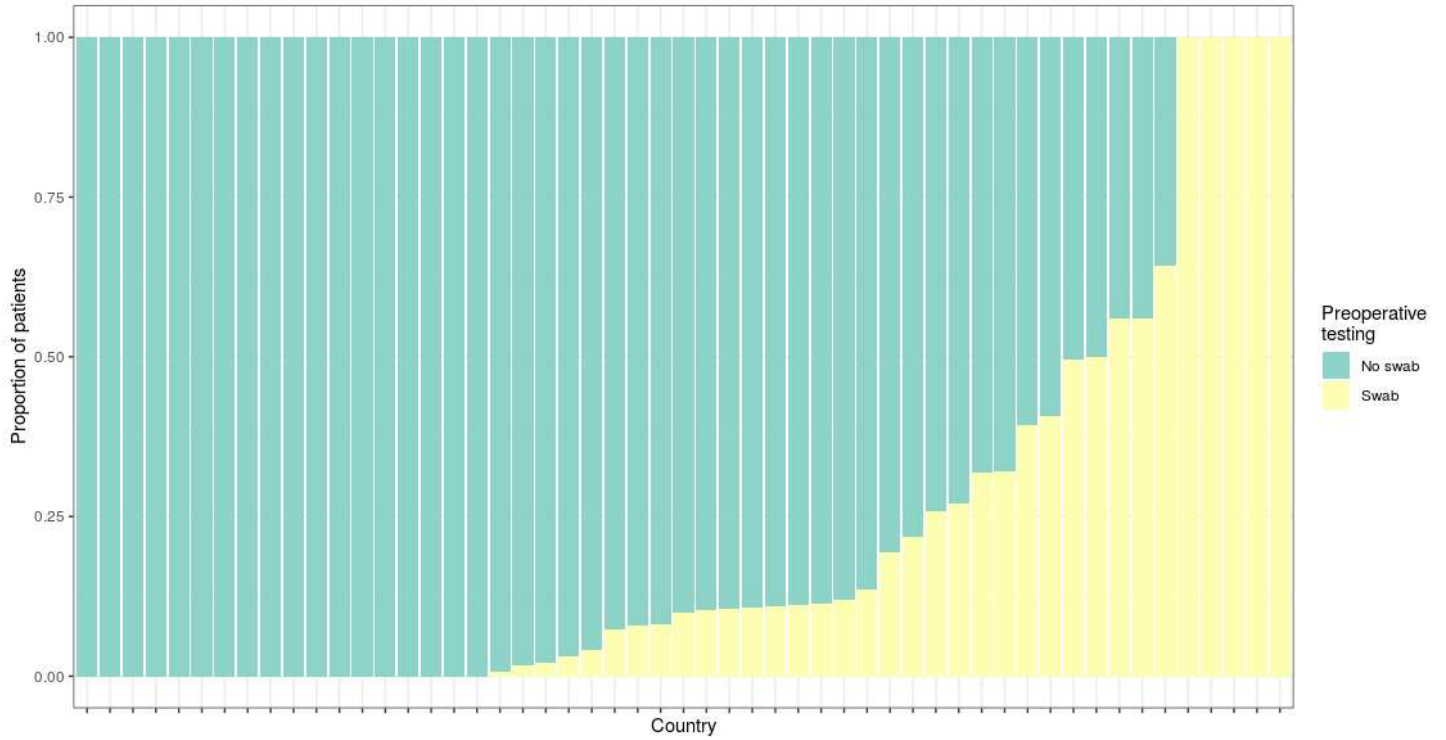
ARR=Absolute risk reduction. NNT=Number needed to test, rounded up to nearest whole person. Grade of surgery was categorised based on the Clinical Coding & Schedule Development Group as either Minor (minor/intermediate) or Major (major/complex major). The community SARS-CoV-2 14-day case notification rate at the time of surgery within each participating hospital's local community was classified as either low (<25 cases per 100,000 population) or high (≥25 cases per 100,000 population). ^a estimate from unadjusted model as adjusted model not possible.

Table 4. Unadjusted outcomes by type of preoperative testing

Postoperative outcomes	Levels	None (n=6481)	Swab only (n=1458)	CT only (n=521)	Swab + CT (n=324)	P-value
Pulmonary complications, n (%)	No	6209 (95.8)	1417 (97.2)	496 (95.2)	316 (97.5)	0.031
	Yes	272 (4.2)	41 (2.8)	25 (4.8)	8 (2.5)	
SARS CoV-2 infection, n (%)	No	6345 (98.4)	1451 (99.5)	516 (99.0)	319 (98.5)	<0.001
	Yes	209 (3.2)	7 (0.5)	5 (1.0)	5 (1.5)	
Mortality, n (%)	No	6272 (96.8)	1437 (99.2)	514 (98.8)	315 (99.4)	0.072
	Yes	104 (1.6)	12 (0.8)	6 (1.2)	2 (0.6)	

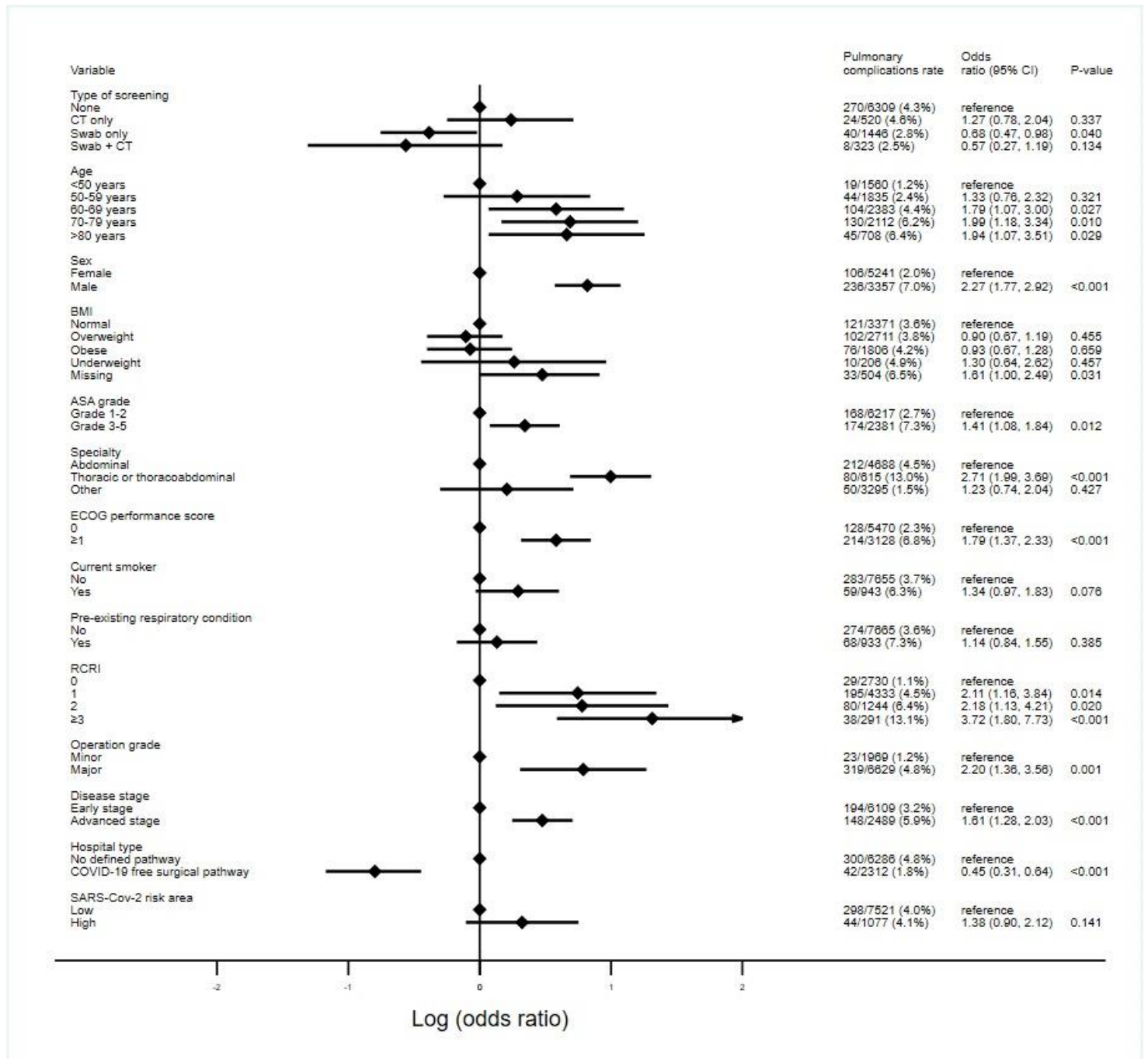
CT=Imaging by computed tomography (CT) thorax.

Figure 1. Variation in preoperative swab testing rates across included countries.



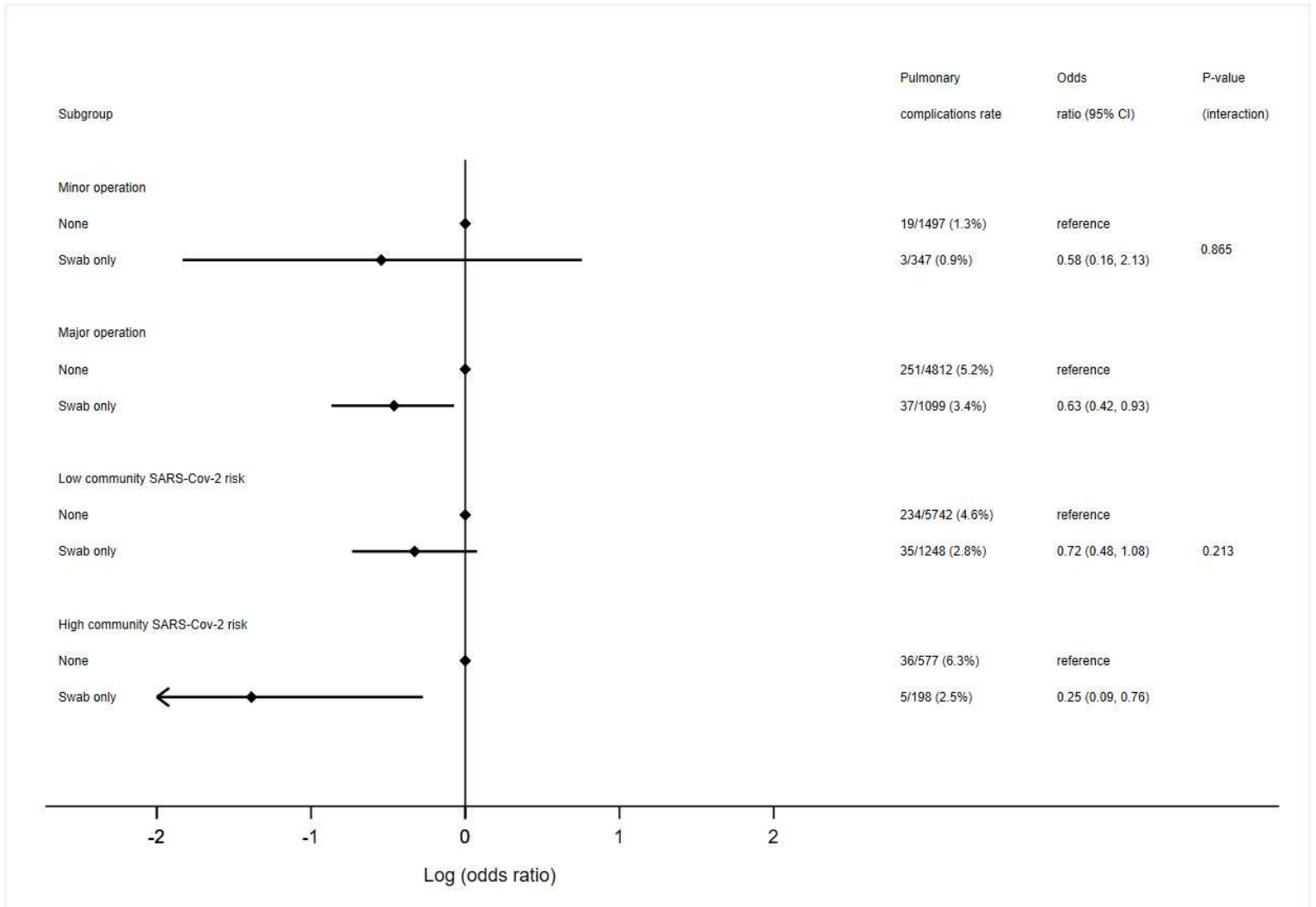
Each bar represents one country. Contributing countries anonymised in accordance with the study protocol. Swab=Nasopharyngeal swab and identification of viral RNA by RT-qPCR, according to local protocols, with or without addition of CT thorax.

Figure 2. Factors associated with postoperative pulmonary complications in the mixed effects model.



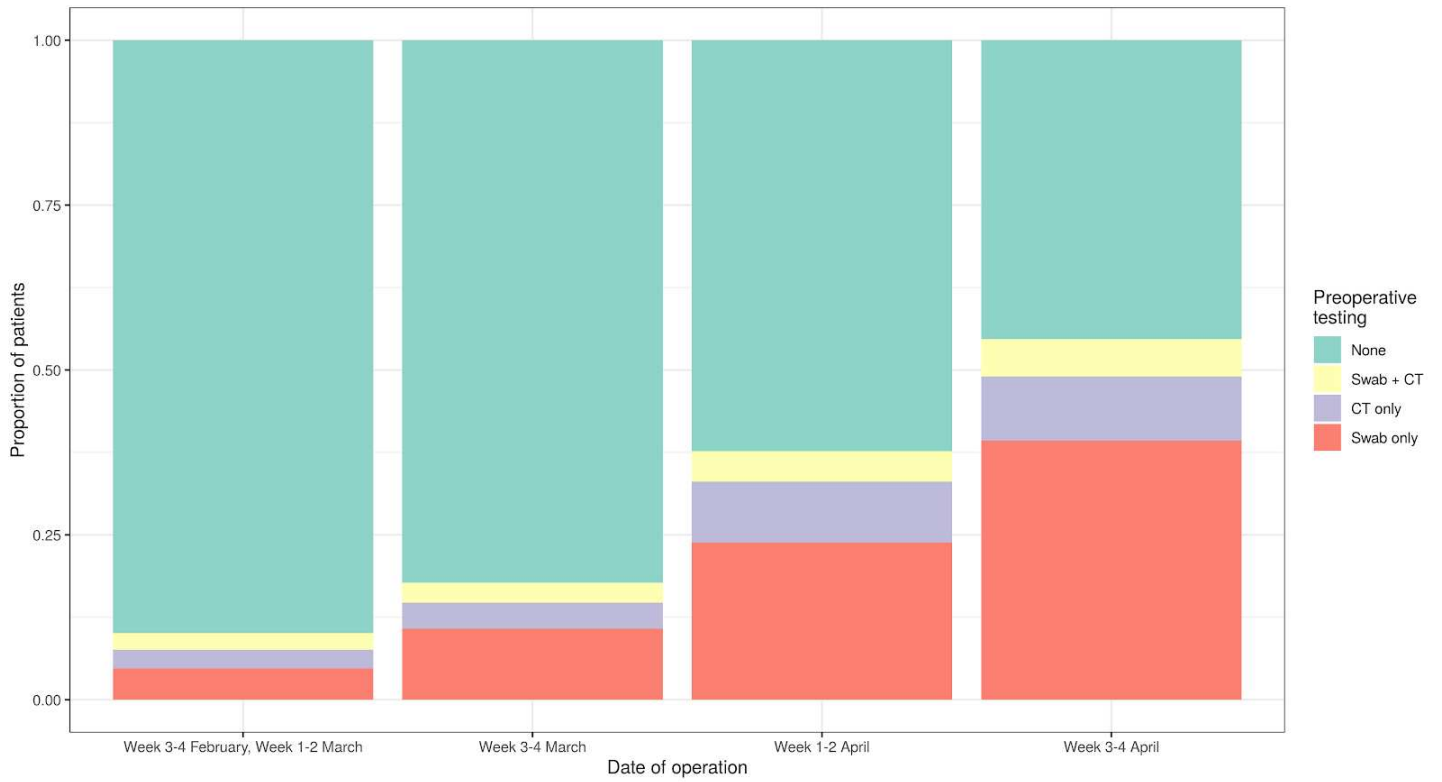
CT=Imaging by computed tomography (CT) thorax. ASA=American Society of Anaesthesiologists. RCRI= Revised Cardiac Risk Index. ECOG=Eastern Cooperative Oncology Group. The rate of missingness for included data variables included in the model was less than 1%, except for Body Mass Index (6%), where missing was included as an additional factor level. Area under the Receiver Operating Characteristic curve for model: 0.81 (excellent discrimination).

Figure 3: Summary of subgroup analyses of swab testing in different patient populations.



Grade of surgery was categorised based on the Clinical Coding & Schedule Development Group as either Minor (minor/intermediate) or Major (major/complex major). The community SARS-CoV-2 risk at the time of surgery within each participating hospital's local community was classified as either low (<25 cases per 100,000 population) or high (≥25 cases per 100,000 population).

Supplementary Figure 1. Preoperative testing rates over time



CT=Imaging by computed tomography (CT) thorax.

Supplementary Table 1. Preoperative testing performed across included operations

Operation	No test	Swab	CT only	Swab + CT
A021 Excision Of Lesion Of Tissue Of Frontal Lobe Of Brain	30 (85.7)	4 (11.4)	1 (2.9)	
A022 Excision Of Lesion Of Tissue Of Temporal Lobe Of Brain	9 (75.0)	3 (25.0)		
A023 Excision Of Lesion Of Tissue Of Parietal Lobe Of Brain	9 (90.0)		1 (10.0)	
A024 Excision Of Lesion Of Tissue Of Occipital Lobe Of Brain	2 (66.7)		1 (33.3)	
A025 Excision Of Lesion Of Tissue Of Cerebellum	7 (100.0)			
A026 Excision Of Lesion Of Tissue Of Brain Stem	1 (50.0)	1 (50.0)		
A032 Stereotactic Ablation Of Tissue Of Thalamus		1 (100.0)		
A042 Open Biopsy Of Lesion Of Tissue Of Temporal Lobe Of Brain	1 (100.0)			
A081 Biopsy Of Lesion Of Tissue Of Frontal Lobe Of Brain		1 (100.0)		
A107 Stereotactic Radiosurgery On Tissue Of Brain	2 (100.0)			
A171 Endoscopic Extirpation Of Lesion Of Ventricle Of Brain	1 (100.0)			
A295 Excision Of Lesion Of Acoustic Nerve (Viii)	3 (75.0)	1 (25.0)		
A298 Excision Of Lesion Of Specified Cranial Nerve	1 (100.0)			
A381 Extirpation Of Lesion Of Meninges Of Cortex Of Brain	9 (100.0)			
A382 Extirpation Of Lesion Of Meninges Of Sphenoidal Ridge Of Cranium	5 (83.3)	1 (16.7)		
A383 Extirpation Of Lesion Of Meninges Of Subfrontal Region Of Br	5 (100.0)			
A384 Extirpation Of Lesion Of Meninges Of Parasagittal Region	5 (100.0)			
A422 Biopsy Of Lesion Of Meninges Of Brain	2 (100.0)			
A511 Extirpation Of Lesion Of Meninges Of Spinal Cord	1 (100.0)			
A604 Radiofrequency Controlled Thermal Destruction Of Peripheral	1 (100.0)			
A611 Excision Of Lesion Of Peripheral Nerve	1 (100.0)			
B041 Excision Of Lesion Of Pituitary Gland	24 (96.0)	1 (4.0)		
B081 Total Thyroidectomy	110 (73.3)	31 (20.7)	7 (4.7)	2 (1.3)
B082 Subtotal Thyroidectomy	2 (100.0)			
B083 Hemithyroidectomy	28 (75.7)	7 (18.9)	2 (5.4)	
B084 Lobectomy Of Thyroid Gland	13 (92.9)		1 (7.1)	
B085 Isthmectomy Of Thyroid Gland		4 (100.0)		
B086 Partial Thyroidectomy	1 (100.0)			
B122 Biopsy Of Lesion Of Thyroid Gland	4 (100.0)			
B142 Global Parathyroidectomy				1 (100.0)
B181 Trans-Sternal Thymectomy	7 (70.0)	1 (10.0)	2 (20.0)	
B182 Transcervical Thymectomy	1 (50.0)	1 (50.0)		
B222 Bilateral Adrenalectomy	1 (100.0)			
B223 Unilateral Adrenalectomy		1 (100.0)		
B271 Total Mastectomy And Excision Of Both Pectoral Muscles And	18 (90.0)	1 (5.0)	1 (5.0)	
B272 Total Mastectomy And Excision Of Both Pectoral Muscles	14 (82.4)		1 (5.9)	2 (11.8)

B273 Total Mastectomy And Excision Of Pectoralis Minor Muscle	47 (95.9)			2 (4.1)
B274 Total Mastectomy	453 (79.9)	73 (12.9)	33 (5.8)	8 (1.4)
B275 Subcutaneous Mastectomy	71 (66.4)	18 (16.8)	14 (13.1)	4 (3.7)
B276 Skin Sparing Mastectomy	104 (88.9)	11 (9.4)	2 (1.7)	
B282 Partial Excision of Breast	582 (74.6)	141 (18.1)	49 (6.3)	8 (1.0)
B292 Reconstruction Of Breast Using Local Flap Of Skin	3 (100.0)			
B294 Reconstruction Of Breast Using Distant Flap Of Skin	1 (100.0)			
B296 Reconstruction Of Breast Using Glandular Remodelling		1 (33.3)	1 (33.3)	1 (33.3)
B297 Reconstruction Of Breast Using Dermoglandular Flap	6 (85.7)		1 (14.3)	
B301 Insertion Of Prosthesis For Breast	1 (100.0)			
B311 Reduction Mammoplasty	4 (66.7)	2 (33.3)		
B322 Biopsy Of Lesion Of Breast	23 (100.0)			
B323 Wire Guided Biopsy Of Lesion Of Breast	68 (94.4)	4 (5.6)		
B393 Reconstruction Of Breast Using Free Deep Inferior Epigastric	1 (100.0)			
B411 Radionuclide Guided Excision Of Lesion Of Breast	27 (96.4)	1 (3.6)		
B412 Radionuclide Guided Partial Excision Of Breast	18 (85.7)	3 (14.3)		
C011 Exenteration Of Orbit	2 (66.7)	1 (33.3)		
C061 Biopsy Of Lesion Of Orbit	1 (100.0)			
C121 Excision Of Lesion Of Eyelid	2 (100.0)			
C391 Excision Of Lesion Of Conjunctiva		1 (100.0)		
D012 Partial Excision Of External Ear	1 (100.0)			
D021 Excision Of Lesion Of External Ear	3 (50.0)	3 (50.0)		
D101 Radical Mastoidectomy	5 (100.0)			
D104 Simple Mastoidectomy	7 (100.0)			
E011 Total Excision Of Nose	4 (100.0)			
E101 Biopsy Of Lesion Of Nose	2 (100.0)			
E132 Excision Of Lesion Of Maxillary Antrum	10 (37.0)	17 (63.0)		
E191 Total Pharyngectomy	2 (100.0)			
E192 Partial Pharyngectomy	1 (33.3)	2 (66.7)		
E242 Endoscopic Extirpation Of Lesion Of Pharynx	2 (100.0)			
E291 Total Laryngectomy	23 (71.9)	7 (21.9)	1 (3.1)	1 (3.1)
E294 Partial Laryngectomy	4 (80.0)	1 (20.0)		
E295 Laryngofissure And Cordectomy Of Vocal Cord	8 (38.1)	10 (47.6)	2 (9.5)	1 (4.8)
E296 Laryngectomy	2 (40.0)	3 (60.0)		
E303 Open Destruction Of Lesion Of Larynx	3 (100.0)			
E361 Diagnostic endoscopic Examination Of Larynx And Biopsy Of Lesion	6 (54.5)	5 (45.5)		
E391 Open Excision Of Lesion Of Trachea	1 (100.0)			
E461 Sleeve Resection Of Bronchus And Anastomosis	2 (50.0)	1 (25.0)		1 (25.0)
E463 Excision Of Lesion Of Bronchus	1 (100.0)			

E541 Total Pneumonectomy	7 (100.0)			
E542 Bilobectomy Of Lung	8 (72.7)	1 (9.1)		2 (18.2)
E543 Lobectomy Of Lung	229 (76.8)	30 (10.1)	19 (6.4)	20 (6.7)
E544 Excision Of Segment Of Lung	63 (67.7)	16 (17.2)	10 (10.8)	4 (4.3)
E545 Partial Lobectomy Of Lung	30 (78.9)	4 (10.5)	1 (2.6)	3 (7.9)
E552 Open Excision Of Lesion Of Lung	2 (50.0)		2 (50.0)	
E593 Biopsy Of Lesion Of Lung	3 (100.0)			
E621 Endoscopic Extirpation Of Lesion Of Mediastinum	1 (100.0)			
E641 Endoscopic Extirpation Of Lesion Of Nasal Cavity	2 (66.7)	1 (33.3)		
F011 Excision Of Vermilion Border Of Lip And Advancement Of Mucosa	1 (33.3)	2 (66.7)		
F021 Excision Of Lesion Of Lip	13 (65.0)	6 (30.0)		1 (5.0)
F221 Total Glossectomy	6 (100.0)			
F222 Partial Glossectomy	70 (72.2)	22 (22.7)	3 (3.1)	2 (2.1)
F231 Excision Of Lesion Of Tongue	42 (62.7)	19 (28.4)	4 (6.0)	2 (3.0)
F241 Biopsy Of Lesion Of Tongue	1 (100.0)			
F281 Excision Of Lesion Of Palate	7 (70.0)	3 (30.0)		
F341 Bilateral Dissection Tonsillectomy	7 (100.0)			
F343 Bilateral Laser Tonsillectomy	1 (100.0)			
F344 Bilateral Excision Of Tonsil	1 (50.0)	1 (50.0)		
F362 Biopsy Of Lesion Of Tonsil	1 (100.0)			
F366 Excision Of Lesion Of Tonsil	13 (72.2)	5 (27.8)		
F421 Biopsy Of Lesion Of Mouth	4 (80.0)	1 (20.0)		
F441 Total Excision Of Parotid Gland	18 (75.0)	6 (25.0)		
F442 Partial Excision Of Parotid Gland	20 (90.9)	2 (9.1)		
F443 Excision Of Parotid Gland	6 (100.0)			
F444 Excision Of Submandibular Gland	3 (75.0)		1 (25.0)	
F445 Excision Of Sublingual Gland	2 (100.0)			
F451 Excision Of Lesion Of Parotid Gland	1 (33.3)	2 (66.7)		
F452 Excision Of Lesion Of Submandibular Gland		1 (50.0)	1 (50.0)	
F454 Excision Of Lesion Of Salivary Gland		1 (100.0)		
G011 Oesophagogastrectomy And Anastomosis Of Oesophagus To Stomach	30 (66.7)	13 (28.9)	1 (2.2)	1 (2.2)
G012 Oesophagogastrectomy And Anastomosis Of Oesophagus To Transposed Jejunum	1 (100.0)			
G013 Oesophagogastrectomy And Anastomosis Of Oesophagus To Jejunum	5 (71.4)	1 (14.3)	1 (14.3)	
G021 Total Oesophagectomy And Anastomosis Of Pharynx To Stomach	15 (68.2)	4 (18.2)	2 (9.1)	1 (4.5)
G022 Total Oesophagectomy/Interposition Of Microvascularly Attached Jejunum	1 (100.0)			
G031 Partial Oesophagectomy And End To End Anastomosis Of Oesophagus	8 (80.0)	1 (10.0)	1 (10.0)	
G033 Partial Oesophagectomy And Anastomosis Of Oesophagus To Transposed Jejunum	4 (66.7)	2 (33.3)		
G034 Partial Oesophagectomy And Anastomosis Of Oesophagus To Jejunum	7 (87.5)	1 (12.5)		
G052 Bypass Of Oesophagus By Anastomosis Of Oesophagus To Stomach	3 (60.0)			2 (40.0)

G271 Total Gastrectomy And Excision Of Surrounding Tissue		1 (100.0)		
G272 Total Gastrectomy And Anastomosis Of Oesophagus To Duodenum	5 (83.3)	1 (16.7)		
G274 Total Gastrectomy And Anastomosis Of Oesophagus To Transposed Jejunum	3 (100.0)			
G275 Total Gastrectomy And Anastomosis Of Oesophagus To Jejunum	44 (49.4)	35 (39.3)	4 (4.5)	6 (6.7)
G281 Partial Gastrectomy And Anastomosis Of Stomach To Duodenum	6 (75.0)	1 (12.5)	1 (12.5)	
G282 Partial Gastrectomy And Anastomosis Of Stomach To Transposed Jejunum	8 (57.1)	2 (14.3)	2 (14.3)	2 (14.3)
G283 Partial Gastrectomy And Anastomosis Of Stomach To Jejunum	56 (57.7)	33 (34.0)	6 (6.2)	2 (2.1)
G285 Sleeve Gastrectomy	7 (87.5)	1 (12.5)		
G292 Open Excision Of Lesion Of Stomach	6 (100.0)			
G454 Fiberoptic Endoscopic Examination Of Upper Gastrointestinal Tract And Staining Of Gastric Mucosa	1 (100.0)			
G491 Gastroduodenectomy	1 (100.0)			
G493 Partial Excision Of Duodenum	2 (50.0)	1 (25.0)	1 (25.0)	
G501 Excision Of Lesion Of Duodenum	1 (100.0)			
G511 Bypass Of Duodenum By Anastomosis Of Stomach To Jejunum	2 (40.0)	2 (40.0)	1 (20.0)	
G582 Total Jejunectomy And Anastomosis Of Duodenum To Ileum	1 (100.0)			
G584 Partial Jejunectomy And Anastomosis Of Jejunum To Ileum	1 (50.0)	1 (50.0)		
G612 Bypass Of Jejunum By Anastomosis Of Jejunum To Ileum	1 (100.0)			
G692 Ileectomy And Anastomosis Of Duodenum To Ileum	1 (100.0)			
G693 Ileectomy And Anastomosis Of Ileum To Ileum	1 (20.0)	2 (40.0)	2 (40.0)	
G694 Ileectomy And Anastomosis Of Ileum To Colon				1 (100.0)
G702 Excision Of Lesion Of Ileum	1 (33.3)		1 (33.3)	1 (33.3)
G721 Anastomosis Of Ileum To Caecum	1 (100.0)			
G723 Anastomosis Of Ileum To Colon	4 (100.0)			
G734 Resection Of Ileocolic Anastomosis	3 (100.0)			
G742 Creation Of Temporary Ileostomy	3 (60.0)	1 (20.0)		1 (20.0)
G743 Creation Of Defunctioning Ileostomy	4 (100.0)			
G753 Closure Of Ileostomy	2 (66.7)	1 (33.3)		
H041 Panproctocolectomy And Ileostomy	7 (70.0)	3 (30.0)		
H042 Panproctocolectomy And Anastomosis Of Ileum To Anus And Creation of Pouch	1 (33.3)		1 (33.3)	1 (33.3)
H051 Total Colectomy And Anastomosis Of Ileum To Rectum	12 (66.7)	1 (5.6)	2 (11.1)	3 (16.7)
H052 Total Colectomy And Ileostomy And Creation Of Rectal Fistula		1 (100.0)		
H053 Total Colectomy And Ileostomy	6 (100.0)			
H061 Extended Right Hemicolectomy And End To End Anastomosis	14 (93.3)	1 (6.7)		
H062 Extended Right Hemicolectomy And Anastomosis Of Ileum To Colon	116 (73.4)	30 (19.0)	10 (6.3)	2 (1.3)
H063 Extended Right Hemicolectomy And Anastomosis	42 (73.7)	13 (22.8)	2 (3.5)	
H064 Extended Right Hemicolectomy And Ileostomy Hfq	5 (100.0)			
H065 Extended Right Hemicolectomy And End To Side Anastomosis	9 (90.0)	1 (10.0)		
H073 Right hemicolectomy and anastomosis	328 (72.4)	79 (17.4)	22 (4.9)	24 (5.3)
H074 Right hemicolectomy and ileostomy	10 (66.7)	2 (13.3)	3 (20.0)	

H081 Transverse Colectomy And End To End Anastomosis	5 (62.5)	2 (25.0)	1 (12.5)	
H082 Transverse Colectomy And Anastomosis Of Ileum To Colon	1 (33.3)	2 (66.7)		
H083 Transverse Colectomy And Anastomosis	2 (66.7)	1 (33.3)		
H084 Transverse Colectomy And Ileostomy				1 (100.0)
H085 Transverse Colectomy And Exteriorisation Of Bowel	1 (50.0)	1 (50.0)		
H086 Transverse Colectomy And End To Side Anastomosis	3 (100.0)			
H091 Left Hemicolectomy And End To End Anastomosis Of Colon To Rectum	44 (60.3)	14 (19.2)	8 (11.0)	7 (9.6)
H092 Left Hemicolectomy And End To End Anastomosis Of Colon To Colon	40 (67.8)	13 (22.0)	6 (10.2)	
H093 Left Hemicolectomy And Anastomosis	21 (84.0)	3 (12.0)	1 (4.0)	
H094 Left Hemicolectomy And Ileostomy	3 (50.0)	2 (33.3)	1 (16.7)	
H095 Left Hemicolectomy And Exteriorisation Of Bowel	8 (61.5)	2 (15.4)	1 (7.7)	2 (15.4)
H096 Left Hemicolectomy And End To Side Anastomosis	6 (66.7)	3 (33.3)		
H101 Sigmoid Colectomy And End To End Anastomosis Of Ileum To Rectum	4 (100.0)			
H102 Sigmoid Colectomy And Anastomosis Of Colon To Rectum	105 (71.9)	23 (15.8)	14 (9.6)	4 (2.7)
H103 Sigmoid Colectomy And Anastomosis	11 (73.3)	4 (26.7)		
H104 Sigmoid Colectomy And Ileostomy	3 (100.0)			
H105 Sigmoid Colectomy And Exteriorisation Of Bowel	10 (58.8)	4 (23.5)	2 (11.8)	1 (5.9)
H106 Sigmoid Colectomy And End To Side Anastomosis	4 (66.7)	2 (33.3)		
H122 Excision Of Lesion Of Colon	1 (100.0)			
H201 Fibreoptic Endoscopic Snare Resection Of Lesion Of Colon	1 (100.0)			
H293 Subtotal Excision Of Colon And Creation Of Colonic Pouch And Anastomosis of Colon to Rectum	1 (100.0)			
H295 Subtotal Excision Of Colon And Anastomosis Of Colon To Ileum	9 (81.8)	1 (9.1)	1 (9.1)	
H321 Resiting Of Colostomy	2 (66.7)	1 (33.3)		
H331 Abdominoperineal Excision Of Rectum And End Colostomy	110 (69.2)	29 (18.2)	14 (8.8)	6 (3.8)
H332 Proctectomy And Anastomosis Of Colon To Anus	6 (85.7)		1 (14.3)	
H333 Anterior Resection Of Rectum And Anastomosis Of Colon To Rectum	286 (67.5)	85 (20.0)	24 (5.7)	29 (6.8)
H334 Anterior Resection Of Rectum And Anastomosis	128 (78.0)	20 (12.2)	8 (4.9)	8 (4.9)
H335 Rectosigmoidectomy And Closure Of Rectal Stump And Exteriorisation of Bowel	9 (75.0)	1 (8.3)	2 (16.7)	
H336 Anterior Resection Of Rectum And Exteriorisation Of Bowel	88 (71.0)	22 (17.7)	11 (8.9)	3 (2.4)
H337 Perineal Resection Of Rectum	2 (100.0)			
H341 Open Excision Of Lesion Of Rectum	2 (66.7)		1 (33.3)	
H401 Trans-Sphincteric Excision Of Mucosa Of Rectum	2 (100.0)			
H402 Trans-Sphincteric Excision Of Lesion Of Rectum	1 (100.0)			
H404 Trans-Sphincteric Anastomosis Of Colon To Anus	1 (100.0)			
H411 Rectosigmoidectomy And Peranal Anastomosis	6 (60.0)	1 (10.0)	2 (20.0)	1 (10.0)
H412 Peranal Excision Of Lesion Of Rectum	12 (60.0)	4 (20.0)	1 (5.0)	3 (15.0)
H413 Peranal Destruction Of Lesion Of Rectum		1 (100.0)		
H414 Peranal Mucosal Proctectomy And Endoanal Anastomosis		1 (100.0)		
J015 Orthotopic Transplantation Of Whole Liver	3 (60.0)	1 (20.0)	1 (20.0)	

J021 Right Hemihepatectomy	35 (74.5)	10 (21.3)	1 (2.1)	1 (2.1)
J022 Left Hemihepatectomy	35 (71.4)	10 (20.4)	2 (4.1)	2 (4.1)
J023 Resection Of Segment Of Liver	78 (70.3)	18 (16.2)	13 (11.7)	2 (1.8)
J024 Wedge Excision Of Liver	41 (65.1)	9 (14.3)	11 (17.5)	2 (3.2)
J026 Extended Right Hemihepatectomy	9 (52.9)	6 (35.3)	2 (11.8)	
J027 Extended Left Hemihepatectomy	3 (42.9)	2 (28.6)	1 (14.3)	1 (14.3)
J031 Excision Of Lesion Of Liver	25 (83.3)	4 (13.3)		1 (3.3)
J033 Thermal Ablation Of Single Lesion Of Liver	5 (100.0)			
J035 Excision Of Multiple Lesions Of Liver	15 (45.5)	14 (42.4)	4 (12.1)	
J053 Open Wedge Biopsy Of Lesion Of Liver	3 (100.0)			
J083 Endoscopic Microwave Ablation Lesion Liver Using Laparoscope	2 (100.0)			
J092 Laparoscopic Ultrasound Examination Of Liver And Biopsy Of L	1 (100.0)			
J181 Total Cholecystectomy And Excision Of Surrounding Tissue	2 (100.0)			
J182 Total Cholecystectomy And Exploration Of Common Bile Duct	1 (100.0)			
J183 Total Cholecystectomy	5 (83.3)			1 (16.7)
J273 Partial Excision/Bile Duct And Anastomosis/Bile Duct To Jejunum	1 (100.0)			
J281 Excision Of Lesion Of Bile Duct	1 (100.0)			
J292 Anastomosis Of Hepatic Duct To Jejunum	2 (66.7)	1 (33.3)		
J302 Anastomosis Of Common Bile Duct To Transposed Jejunum	1 (100.0)			
J303 Anastomosis Of Common Bile Duct To Jejunum	1 (100.0)			
J551 Total Pancreatectomy And Excision Of Surrounding Tissue	10 (66.7)	5 (33.3)		
J561 Pancreaticoduodenectomy And Excision Of Surrounding Tissue	118 (77.1)	28 (18.3)	6 (3.9)	1 (0.7)
J564 Subtotal Excision Of Head Of Pancreas With Preservation Of Duodenum and Drainage	2 (100.0)			
J571 Subtotal Pancreatectomy	13 (81.2)	1 (6.2)		2 (12.5)
J573 Left Pancreatectomy	27 (75.0)	9 (25.0)		
J575 Excision Of Tail Of Pancreas	7 (77.8)	1 (11.1)	1 (11.1)	
J582 Excision Of Lesion Of Pancreas	4 (100.0)			
J671 Diagnostic Percutaneous Aspiration Of Lesion Of Pancreas	1 (100.0)			
J692 Total Splenectomy		1 (100.0)		
M021 Nephrectomy And Excision Of Perirenal Tissue	35 (76.1)	5 (10.9)	5 (10.9)	1 (2.2)
M022 Nephroureterectomy	27 (69.2)	6 (15.4)	6 (15.4)	
M023 Bilateral Nephrectomy		1 (100.0)		
M025 Nephrectomy	67 (84.8)	5 (6.3)	1 (1.3)	6 (7.6)
M182 Excision Of Segment Of Ureter	2 (100.0)			
M183 Secondary Ureterectomy			1 (100.0)	
M341 Cystoprostatectomy	28 (93.3)	1 (3.3)	1 (3.3)	
M342 Cystourethrectomy	3 (100.0)			
M343 Cystectomy	16 (84.2)	1 (5.3)	1 (5.3)	1 (5.3)
M344 Simple Cystectomy	2 (100.0)			

M421 Endoscopic Resection Of Lesion Of Bladder	42 (97.7)			1 (2.3)
M422 Endoscopic Cauterisation Of Lesion Of Bladder	5 (100.0)			
M423 Endoscopic Destruction Of Lesion Of Bladder	2 (100.0)			
M455 Diagnostic endoscopic Examination Of Bladder Using Rigid Cystoscope	8 (100.0)			
M611 Total Excision Of Prostate And Capsule Of Prostate	48 (100.0)			
M612 Retropubic Prostatectomy	54 (79.4)	2 (2.9)	10 (14.7)	2 (2.9)
M614 Perineal Prostatectomy	10 (90.9)		1 (9.1)	
M651 Endoscopic Resection Of Prostate Using Electrotome	1 (100.0)			
M653 Endoscopic Resection Of Prostate	3 (75.0)	1 (25.0)		
M723 Excision Of Lesion Of Urethra				1 (100.0)
N261 Total Amputation Of Penis	2 (100.0)			
N271 Excision Of Lesion Of Penis		1 (100.0)		
Other (not otherwise classified)	107 (77.5)	20 (14.5)		11 (8.0)
P051 Total Excision Of Vulva	10 (50.0)	5 (25.0)	3 (15.0)	2 (10.0)
P052 Partial Excision Of Vulva	17 (68.0)	4 (16.0)	1 (4.0)	3 (12.0)
P054 Excision Of Lesion Of Vulva	12 (92.3)	1 (7.7)		
P065 Excision Of Lesion Of Labia	1 (100.0)			
P091 Biopsy Of Lesion Of Vulva	1 (100.0)			
P201 Excision Of Lesion Of Vagina				1 (100.0)
P317 Extirpation Of Lesion Of Pouch Of Douglas	1 (100.0)			
Q011 Amputation Of Cervix Uteri	2 (50.0)	1 (25.0)	1 (25.0)	
Q013 Excision Of Lesion Of Cervix Uteri	1 (33.3)		2 (66.7)	
Q014 Large Loop Excision Of Transformation Zone	1 (100.0)			
Q033 Cone Biopsy Of Cervix Uteri	4 (100.0)			
Q071 Abdominal Hysterocolpectomy And Excision Of Periuterine Tissue	21 (84.0)	1 (4.0)	1 (4.0)	2 (8.0)
Q072 Abdominal Hysterectomy And Excision Of Periuterine Tissue	213 (67.6)	55 (17.5)	39 (12.4)	8 (2.5)
Q073 Abdominal Hysterocolpectomy	32 (86.5)	3 (8.1)		2 (5.4)
Q074 Total Abdominal Hysterectomy	178 (71.2)	22 (8.8)	11 (4.4)	39 (15.6)
Q075 Subtotal Abdominal Hysterectomy	2 (100.0)			
Q081 Vaginal Hysterocolpectomy And Excision Of Periuterine Tissue		1 (100.0)		
Q082 Vaginal Hysterectomy And Excision Of Periuterine Tissue	2 (50.0)	2 (50.0)		
Q083 Vaginal Hysterocolpectomy	1 (50.0)	1 (50.0)		
Q176 Endoscopic Microwave Ablation Of Endometrium		1 (100.0)		
Q181 Diagnostic Endoscopic Examination Of Uterus And Biopsy Of Le	1 (100.0)			
Q221 Bilateral Salpingoophorectomy	31 (70.5)	4 (9.1)	6 (13.6)	3 (6.8)
Q231 Unilateral Salpingoophorectomy	10 (76.9)			3 (23.1)
Q233 Unilateral Salpingectomy	2 (66.7)			1 (33.3)
Q235 Unilateral Oophorectomy	1 (50.0)	1 (50.0)		
Q432 Excision Of Lesion Of Ovary	4 (44.4)	3 (33.3)		2 (22.2)

Q501 Diagnostic Endoscopic Examination Of Ovary And Biopsy Of Lesion	2 (100.0)			
S022 Abdominolipectomy	1 (100.0)			
S083 Curettage Of Lesion Of Skin Of Head Or Neck	1 (100.0)			
S151 Biopsy Of Lesion Of Skin Of Head Or Neck	24 (50.0)	24 (50.0)		
S152 Biopsy Of Lesion Of Skin	6 (100.0)			
T013 Excision Of Lesion Of Chest Wall	2 (33.3)	1 (16.7)	3 (50.0)	
T071 Decortication Of Pleura	1 (50.0)	1 (50.0)		
T072 Open Excision Of Lesion Of Pleura	1 (50.0)	1 (50.0)		
T102 Endoscopic Pleurodesis Using Talc				1 (100.0)
T111 Diagnostic endoscopic Examination Of Pleura And Biopsy Of Lesion	1 (100.0)			
T301 Reopening Of Abdomen And Re-Exploration Of Intra-abdominal Operation Site	1 (100.0)			
T303 Reopening Of Abdomen	1 (50.0)	1 (50.0)		
T304 Opening Of Abdomen And Exploration Of Groin	4 (100.0)			
T331 Open Excision Of Lesion Of Peritoneum	7 (77.8)		2 (22.2)	
T332 Open Destruction Of Lesion Of Peritoneum	2 (66.7)			1 (33.3)
T362 Excision Of Lesion Of Omentum	7 (77.8)	1 (11.1)		1 (11.1)
T364 Biopsy Of Lesion Of Omentum	5 (83.3)			1 (16.7)
T371 Excision Of Lesion Of Mesentery Of Small Intestine			1 (100.0)	
T381 Excision Of Lesion Of Mesentery Of Colon	1 (100.0)			
T383 Biopsy Of Lesion Of Mesentery Of Colon	1 (50.0)	1 (50.0)		
T391 Excision Of Lesion Of Posterior Peritoneum	12 (80.0)	2 (13.3)		1 (6.7)
T393 Biopsy Of Lesion Of Posterior Peritoneum	2 (25.0)			6 (75.0)
T421 Endoscopic Resection Of Lesion Of Peritoneum			1 (100.0)	
T423 Endoscopic Division Of Adhesions Of Peritoneum				1 (100.0)
T425 Endoscopic Excision Of Peritoneum	2 (100.0)			
T431 Diag.endo.exam/Peritoneum And Biopsy Of Lesion Of Peritoneum	3 (100.0)			
T432 Diag.endo.exam/Peritoneum/Biopsy/Lesion Intra-Abdominal Organ		1 (100.0)		
T482 Introduction Of Cytotoxic Substance Into Peritoneal Cavity	5 (62.5)			3 (37.5)
T512 Excision Of Fascia Of Pelvis	2 (100.0)			
T531 Excision Of Lesion Of Fascia	1 (50.0)		1 (50.0)	
T772 Wide Excision Of Muscle	16 (72.7)	4 (18.2)	2 (9.1)	
T851 Block Dissection Of Cervical Lymph Nodes	55 (71.4)	16 (20.8)	5 (6.5)	1 (1.3)
T852 Block Dissection Of Axillary Lymph Nodes	27 (67.5)	11 (27.5)	2 (5.0)	
T853 Block Dissection Of Mediastinal Lymph Nodes	2 (100.0)			
T854 Block Dissection Of Para-Aortic Lymph Nodes	13 (86.7)	1 (6.7)		1 (6.7)
T855 Block Dissection Of Inguinal Lymph Nodes	10 (100.0)			
T856 Block Dissection Of Pelvic Lymph Nodes	1 (50.0)		1 (50.0)	
T861 Sampling Of Cervical Lymph Nodes		1 (50.0)		1 (50.0)
T862 Sampling Of Axillary Lymph Nodes		1 (100.0)		

T866 Sampling Of Para-Aortic Lymph Nodes	3 (100.0)			
T872 Excision Or Biopsy Of Cervical Lymph Node	3 (50.0)	3 (50.0)		
T873 Excision Or Biopsy Of Axillary Lymph Node	10 (66.7)	5 (33.3)		
T874 Excision Or Biopsy Of Mediastinal Lymph Node	3 (100.0)			
T875 Excision Or Biopsy Of Para-Aortic Lymph Node	2 (100.0)			
T876 Excision Or Biopsy Of Porta Hepatis Lymph Node	1 (100.0)			
T877 Excision Or Biopsy Of Inguinal Lymph Node		1 (100.0)		
T911 Biopsy Of Sentinel Lymph Node	13 (52.0)	10 (40.0)		2 (8.0)
T926 Excision Of Lymphoedematous Tissue		1 (100.0)		
T962 Excision Of Lesion Of Soft Tissue	67 (72.0)	17 (18.3)	6 (6.5)	3 (3.2)
T966 Biopsy Of Soft Tissue	1 (100.0)			
V032 Reopening Of Cranium And Re-Exploration Of Intracranial Operation Site	3 (75.0)	1 (25.0)		
V037 Decompressive Craniectomy	5 (100.0)			
V071 Extensive Excision Of Bone Of Face	1 (100.0)			
V072 Partial Excision Of Bone Of Face	1 (33.3)	2 (66.7)		
V073 Excision Of Lesion Of Bone Of Face	2 (100.0)			
V074 Excision Of Lesion Of Infratemporal Fossa	1 (100.0)			
V141 Hemimandibulectomy	19 (70.4)	5 (18.5)	2 (7.4)	1 (3.7)
V142 Extensive Excision Of Mandible	11 (45.8)	12 (50.0)	1 (4.2)	
V143 Partial Excision Of Mandible	6 (42.9)	8 (57.1)		
V144 Excision Of Lesion Of Mandible	12 (48.0)	13 (52.0)		
V191 Reconstruction Of Mandible	3 (100.0)			
V194 Biopsy Of Lesion Of Mandible	1 (100.0)			
V433 Excision Of Lesion Of Lumbar Vertebra	2 (100.0)			
W062 Total Excision Of Rib	1 (100.0)			
W067 Total Excision Of Pelvic Bones		1 (100.0)		
W091 Excision Of Lesion Of Bone	6 (100.0)			
W095 Curettage Of Tumour Of Bone And Graft	2 (100.0)			
W096 Curettage Of Tumour Of Bone	1 (100.0)			
W097 Excision Of Tumour Of Bone	7 (53.8)		3 (23.1)	3 (23.1)
X071 Forequarter Amputation	1 (50.0)		1 (50.0)	
X073 Amputation Of Arm Above Elbow	2 (100.0)			
X091 Hindquarter Amputation	1 (33.3)		1 (33.3)	1 (33.3)
X093 Amputation Of Leg Above Knee	2 (66.7)	1 (33.3)		
X095 Amputation Of Leg Below Knee	1 (100.0)			
X141 Total Exenteration Of Pelvis	6 (54.5)	2 (18.2)	2 (18.2)	1 (9.1)
X142 Anterior Exenteration Of Pelvis	6 (100.0)			
X143 Posterior Exenteration Of Pelvis	7 (87.5)	1 (12.5)		
X531 Excision Of Unspecified Organ	5 (71.4)	2 (28.6)		

X532 Excision Of Lesion Of Unspecified Organ	19 (76.0)	5 (20.0)	1 (4.0)	
Y052 Partial Excision Of Organ	2 (100.0)			
Y063 Enucleation Of Lesion Of Organ			1 (100.0)	
Y067 Radiofrequency Excision Of Lesion Of Organ Noc	3 (30.0)	7 (70.0)		
Y201 Stereotactic Biopsy Of Lesion Of Organ Noc	1 (100.0)			

Supplementary Table 2. Factors associated with postoperative pulmonary complications after elective surgery. Model summary presented in forest plot in *Figure 2*.

Factor	Level	Outcome		Unadjusted model (Odds ratio, 95% CI)	Adjusted model (Odds ratio, 95% CI)	P-value
		None (N=8256)	Pulmonary Complications (N=342)			
Screening type	None	6039 (95.7)	270 (4.3)	-	-	-
	Swab only	1406 (97.2)	40 (2.8)	0.67 (0.47 to 0.96)	0.68 (0.47 to 0.98)	0.040
	CT only	496 (95.4)	24 (4.6)	1.20 (0.77 to 1.88)	1.27 (0.78 to 2.04)	0.337
	Swab + CT	315 (97.5)	8 (2.5)	0.61 (0.30 to 1.28)	0.57 (0.27 to 1.19)	0.134
Age	<50 years	1541 (98.8)	19 (1.2)	-	-	-
	50-59 years	1791 (97.6)	44 (2.4)	2.07 (1.23 to 3.47)	1.33 (0.76 to 2.32)	0.321
	60-69 years	2279 (95.6)	104 (4.4)	3.77 (2.34 to 6.06)	1.79 (1.07 to 3.00)	0.027
	70-79 years	1982 (93.8)	130 (6.2)	5.31 (3.32 to 8.50)	1.99 (1.18 to 3.34)	0.010
	≥80 years	663 (93.6)	45 (6.4)	5.42 (3.20 to 9.16)	1.94 (1.07 to 3.51)	0.029
Sex	Female	5135 (98.0)	106 (2.0)	-	-	-
	Male	3121 (93.0)	236 (7.0)	3.51 (2.81 to 4.38)	2.27 (1.77 to 2.92)	<0.001
Body Mass Index	Normal	3250 (96.4)	121 (3.6)	-	-	-
	Overweight	2609 (96.2)	102 (3.8)	1.09 (0.85 to 1.40)	0.90 (0.68 to 1.19)	0.455
	Obese	1730 (95.8)	76 (4.2)	1.19 (0.90 to 1.57)	0.93 (0.67 to 1.28)	0.659
	Underweight	196 (95.1)	10 (4.9)	1.24 (0.64 to 2.40)	1.30 (0.64 to 2.62)	0.457
	Missing	471 (93.5)	33 (6.5)	1.45 (0.99 to 2.13)	1.61 (1.00 to 2.49)	0.031
ASA Grade	Grade 1-2	6049 (97.3)	168 (2.7)	-	-	-
	Grade 3-5	2207 (92.7)	174 (7.3)	2.87 (2.32 to 3.55)	1.41 (1.08 to 1.84)	0.012
Specialty	Abdominal	4476 (95.5)	212 (4.5)	-	-	-
	Thoracic or thoracoabdominal	535 (87.0)	80 (13.0)	2.69 (2.05 to 3.53)	2.71 (1.99 to 3.69)	<0.001
	Other	3245 (98.5)	50 (1.5)	0.33 (0.24 to 0.44)	1.23 (0.74 to 2.04)	0.427
ECOG Performance Score	0	5342 (97.7)	128 (2.3)	-	-	-
	≥1	2914 (93.2)	214 (6.8)	2.83 (2.29 to 3.50)	1.79 (1.37 to 2.33)	<0.001
Current smoker	No	7372 (96.3)	283 (3.7)	-	-	-
	Yes	884 (93.7)	59 (6.3)	1.57 (1.19 to 2.08)	1.34 (0.97 to 1.83)	0.076
Pre-existing respiratory condition	No	7391 (96.4)	274 (3.6)	-	-	-
	Yes	865 (92.7)	68 (7.3)	2.05 (1.58 to 2.66)	1.14 (0.84 to 1.55)	0.385
Revised Cardiac Risk Index	0	2701 (98.9)	29 (1.1)	-	-	-
	1	4138 (95.5)	195 (4.5)	4.05 (2.80 to 5.85)	2.11 (1.16 to 3.84)	0.014
	2	1164 (93.6)	80 (6.4)	6.04 (4.03 to 9.05)	2.18 (1.13 to 4.21)	0.020
	≥3	253 (86.9)	38 (13.1)	12.65 (7.85 to 20.38)	3.72 (1.80 to 7.73)	<0.001
Operation grade	Minor	1946 (98.8)	23 (1.2)	-	-	-
	Major	6310 (95.2)	319 (4.8)	4.01 (4.00 to 4.02)	2.20 (1.36 to 3.56)	0.001
Disease stage	Early stage	5915 (96.8)	194 (3.2)	-	-	-
	Advanced stage	2341 (94.1)	148 (5.9)	1.84 (1.49 to 2.26)	1.61 (1.28 to 2.03)	<0.001
Hospital type	No defined pathway	5986 (95.2)	300 (4.8)	-	-	-
	COVID-19 free surgical pathway	2270 (98.2)	42 (1.8)	0.48 (0.35 to 0.66)	0.45 (0.31 to 0.64)	<0.001
Community SARS-Cov-2 risk	Low	7223 (96.0)	298 (4.0)	-	-	-
	High	1033 (95.9)	44 (4.1)	1.04 (0.71 to 1.51)	1.38 (0.90 to 2.12)	0.141

Data included from 8598 patients with complete data. COVID-19=Coronavirus disease 2019. ASA=American Society of Anaesthesiologists. ECOG=Eastern Cooperative Oncology Group. Percentages calculated as a proportion of row total. Area under the Receiver Operating Characteristic curve for model: 0.81 (excellent discrimination). A summary of a sensitivity analysis for potentially missing data is presented in *Supplementary Table 7*.

Supplementary Table 3. Subgroup analysis of factors associated with postoperative pulmonary complications after elective surgery in high risk areas.

Factor	Level	Outcome		Unadjusted model (Odds ratio, 95% CI)	Adjusted model (Odds ratio, 95% CI)	P-value
		None (N=724)	Pulmonary Complications (N=41)			
Screening type	None	531 (93.7)	36 (6.3)	-	-	-
	Swab only	193 (97.5)	5 (2.5)	0.38 (0.15 to 0.99)	0.25 (0.09 to 0.76)	0.014
Age	<50 years	115 (96.6)	4 (3.4)	-	-	-
	50-59 years	149 (98.7)	2 (1.3)	0.38 (0.07 to 2.14)	0.21 (0.03 to 1.23)	0.083
	60-69 years	201 (93.1)	15 (6.9)	2.14 (0.69 to 6.61)	1.04 (0.30 to 3.62)	0.955
	70-79 years	178 (92.2)	15 (7.8)	2.43 (0.79 to 7.50)	0.79 (0.21 to 3.02)	0.731
	≥80 years	81 (94.2)	5 (5.8)	1.77 (0.46 to 6.81)	0.52 (0.11 to 2.55)	0.421
Sex	Female	467 (97.3)	13 (2.7)	-	-	-
	Male	257 (90.2)	28 (9.8)	3.91 (1.99 to 7.69)	2.77 (1.28 to 5.99)	0.010
Body Mass Index	Normal	346 (94.5)	20 (5.5)	-	-	-
	Overweight	209 (96.3)	8 (3.7)	0.66 (0.29 to 1.53)	0.47 (0.19 to 1.16)	0.102
	Obese	114 (96.6)	4 (3.4)	0.61 (0.20 to 1.81)	0.50 (0.15 to 1.59)	0.239
	Underweight	11 (84.6)	2 (15.4)	3.15 (0.65 to 15.16)	5.20 (0.89 to 30.47)	0.068
	Missing	44 (86.3)	7 (13.7)	2.75 (1.10 to 6.88)	1.47 (0.50 to 4.33)	0.486
ASA Grade	Grade 1-2	544 (96.6)	19 (3.4)	-	-	-
	Grade 3-5	180 (89.1)	22 (10.9)	3.50 (1.85 to 6.61)	2.86 (1.23 to 6.65)	0.014
Specialty	Abdominal	362 (92.3)	30 (7.7)	-	-	-
	Thoracic or thoracoabdominal	15 (83.3)	3 (16.7)	2.41 (0.66 to 8.81)	2.59 (0.60 to 11.20)	0.204
	Other	347 (97.7)	8 (2.3)	0.28 (0.13 to 0.62)	0.56 (0.10 to 2.97)	0.491
ECOG Performance Score	0	423 (95.9)	18 (4.1)	-	-	-
	≥1	301 (92.9)	23 (7.1)	1.80 (0.95 to 3.39)	1.16 (0.49 to 2.75)	0.739
Current smoker	No	638 (94.9)	34 (5.1)	-	-	-
	Yes	86 (92.5)	7 (7.5)	1.53 (0.66 to 3.55)	1.09 (0.41 to 2.90)	0.863
Pre-existing respiratory condition	No	657 (94.5)	38 (5.5)	-	-	-
	Yes	67 (95.7)	3 (4.3)	0.77 (0.23 to 2.58)	0.24 (0.06 to 0.93)	0.039
Revised Cardiac Risk Index	0	300 (98.0)	6 (2.0)	-	-	-
	1	315 (92.9)	24 (7.1)	3.81 (1.54 to 9.45)	1.22 (0.21 to 7.28)	0.826
	2	88 (92.6)	7 (7.4)	3.98 (1.30 to 12.14)	0.65 (0.08 to 5.25)	0.687
	≥3	21 (84.0)	4 (16.0)	9.52 (2.49 to 36.38)	1.00 (0.10 to 10.31)	0.998
Operation grade	Minor	206 (98.6)	3 (1.4)	-	-	-
	Major	518 (93.2)	38 (6.8)	5.04 (1.54 to 16.50)	2.53 (0.61 to 10.41)	0.199
Disease stage	Early stage	546 (95.6)	25 (4.4)	-	-	-
	Advanced stage	178 (91.8)	16 (8.2)	1.96 (1.02 to 3.77)	1.35 (0.65 to 2.82)	0.424
Hospital type	No defined pathway	499 (93.1)	37 (6.9)	-	-	-
	COVID-19 free surgical pathway	225 (98.3)	4 (1.7)	0.24 (0.08 to 0.68)	0.23 (0.08 to 0.68)	0.008

Data included from 765 patients with complete data. COVID-19=Coronavirus disease 2019. ASA=American Society of Anaesthesiologists. ECOG=Eastern Cooperative Oncology Group. Percentages calculated as a proportion of row total. Area under the Receiver Operating Characteristic curve for model: 0.85 (excellent discrimination).

Supplementary Table 4. Subgroup analysis of factors associated with postoperative pulmonary complications after elective surgery in low risk areas.

Factor	Level	Outcome		Unadjusted model (Odds ratio, 95% CI)	Adjusted model (Odds ratio, 95% CI)	P-value
		None (N=6721)	Pulmonary Complications (N=269)			
Screening type	None	5508 (95.9)	234 (4.1)	-	-	-
	Swab only	1213 (97.2)	35 (2.8)	0.66 (0.45 to 0.97)	0.72 (0.48 to 1.08)	0.108
Age	<50 years	1280 (98.9)	14 (1.1)	-	-	-
	50-59 years	1444 (97.5)	37 (2.5)	2.24 (1.21 to 4.13)	1.51 (0.80 to 2.86)	0.205
	60-69 years	1856 (95.9)	79 (4.1)	3.69 (2.09 to 6.52)	1.79 (0.98 to 3.26)	0.057
	70-79 years	1614 (93.9)	104 (6.1)	5.43 (3.10 to 9.51)	2.09 (1.15 to 3.80)	0.016
	≥80 years	527 (93.8)	35 (6.2)	5.51 (2.94 to 10.33)	2.11 (1.06 to 4.17)	0.032
Sex	Female	4166 (98.1)	81 (1.9)	-	-	-
	Male	2555 (93.1)	188 (6.9)	3.67 (2.81 to 4.80)	2.31 (1.74 to 3.06)	<0.001
Body Mass Index	Normal	2578 (96.7)	87 (3.3)	-	-	-
	Overweight	2101 (96.1)	86 (3.9)	1.26 (0.93 to 1.70)	1.05 (0.76 to 1.45)	0.762
	Obese	1466 (95.8)	64 (4.2)	1.36 (0.97 to 1.89)	1.01 (0.70 to 1.43)	0.977
	Underweight	162 (95.9)	7 (4.1)	1.26 (0.58 to 2.77)	1.12 (0.49 to 2.56)	0.796
	Missing	414 (94.3)	25 (5.7)	1.59 (0.99 to 2.55)	1.70 (1.03 to 2.81)	0.037
ASA Grade	Grade 1-2	4860 (97.5)	126 (2.5)	-	-	-
	Grade 3-5	1861 (92.9)	143 (7.1)	3.08 (2.39 to 3.97)	1.39 (1.03 to 1.88)	0.029
Specialty	Abdominal	3570 (95.7)	162 (4.3)	-	-	-
	Thoracic or thoracoabdominal	446 (86.6)	69 (13.4)	3.13 (2.29 to 4.27)	2.83 (2.01 to 3.98)	<0.001
	Other	2705 (98.6)	38 (1.4)	0.34 (0.24 to 0.49)	1.27 (0.72 to 2.24)	0.407
ECOG Performance Score	0	4376 (97.8)	97 (2.2)	-	-	-
	≥1	2345 (93.2)	172 (6.8)	3.19 (2.47 to 4.12)	1.85 (1.37 to 2.49)	<0.001
Current smoker	No	6006 (96.4)	223 (3.6)	-	-	-
	Yes	715 (94.0)	46 (6.0)	1.64 (1.18 to 2.28)	1.40 (0.98 to 2.01)	0.067
Pre-existing respiratory condition	No	6005 (96.7)	208 (3.3)	-	-	-
	Yes	716 (92.1)	61 (7.9)	2.21 (1.64 to 2.98)	1.39 (1.00 to 1.93)	0.052
Revised Cardiac Risk Index	0	2236 (99.1)	21 (0.9)	-	-	-
	1	3324 (95.7)	150 (4.3)	4.37 (2.76 to 6.91)	2.20 (1.12 to 4.34)	0.023
	2	951 (93.3)	68 (6.7)	7.25 (4.42 to 11.89)	2.49 (1.19 to 5.20)	0.015
	≥3	210 (87.5)	30 (12.5)	13.94 (7.79 to 24.94)	3.99 (1.76 to 9.06)	0.001
Operation grade	Minor	1616 (98.8)	19 (1.2)	-	-	-
	Major	5105 (95.3)	250 (4.7)	4.04 (2.53 to 6.44)	2.12 (1.25 to 3.62)	0.006
Disease stage	Early stage	4838 (97.0)	151 (3.0)	-	-	-
	Advanced stage	1883 (94.1)	118 (5.9)	1.94 (1.51 to 2.48)	1.70 (1.30 to 2.20)	<0.001
Hospital type	No defined pathway	5174 (95.6)	240 (4.4)	-	-	-
	COVID-19 free surgical pathway	1547 (98.2)	29 (1.8)	0.50 (0.33 to 0.76)	0.53 (0.34 to 0.81)	0.003

Data included from 6990 patients with complete data. COVID-19=Coronavirus disease 2019. ASA=American Society of Anaesthesiologists. ECOG=Eastern Cooperative Oncology Group. Percentages calculated as a proportion of row total. Area under the Receiver Operating Characteristic curve for model: 0.81 (excellent discrimination).

Supplementary Table 5. Subgroup analysis of factors associated with postoperative pulmonary complications after major surgery

Factor	Level	Outcome		Unadjusted model (Odds ratio, 95% CI)	Adjusted model (Odds ratio, 95% CI)	P-value
		None (N=5623)	Pulmonary Complications (N=288)			
Screening type	None	4561 (94.8)	251 (5.2)	-	-	-
	Swab only	1062 (96.6)	37 (3.4)	0.58 (0.40 to 0.85)	0.63 (0.42 to 0.93)	0.019
Age	<50 years	1022 (98.4)	17 (1.6)	-	-	-
	50-59 years	1149 (97.0)	35 (3.0)	1.70 (0.95 to 3.04)	1.12 (0.61 to 2.05)	0.717
	60-69 years	1569 (94.9)	85 (5.1)	3.00 (1.78 to 5.07)	1.51 (0.87 to 2.63)	0.144
	70-79 years	1426 (92.6)	114 (7.4)	4.25 (2.54 to 7.11)	1.75 (1.00 to 3.04)	0.05
	≥80 years	457 (92.5)	37 (7.5)	4.29 (2.39 to 7.70)	1.63 (0.86 to 3.10)	0.135
Sex	Female	3281 (97.6)	82 (2.4)	-	-	-
	Male	2342 (91.9)	206 (8.1)	3.38 (2.60 to 4.40)	2.45 (1.85 to 3.23)	<0.001
BMI	Normal	2213 (95.7)	99 (4.3)	-	-	-
	Overweight	1746 (95.2)	88 (4.8)	1.15 (0.86 to 1.55)	0.96 (0.70 to 1.31)	0.782
	Obese	1224 (95.1)	63 (4.9)	1.18 (0.85 to 1.64)	0.93 (0.66 to 1.32)	0.692
	Underweight	133 (93.7)	9 (6.3)	1.55 (0.77 to 3.16)	1.55 (0.73 to 3.29)	0.256
	Missing	307 (91.4)	29 (8.6)	1.93 (1.24 to 3.02)	1.68 (1.05 to 2.70)	0.03
ASA Grade	Grade 1-2	3993 (96.8)	131 (3.2)	-	-	-
	Grade 3-5	1630 (91.2)	157 (8.8)	2.99 (2.34 to 3.82)	1.60 (1.19 to 2.13)	0.002
Specialty	Abdominal	3620 (95.0)	189 (5.0)	-	-	-
	Thoracic or thoracoabdominal	456 (86.5)	71 (13.5)	2.90 (2.13 to 3.93)	2.63 (1.88 to 3.66)	<0.001
	Other	1547 (98.2)	28 (1.8)	0.40 (0.27 to 0.60)	1.02 (0.53 to 1.96)	0.960
ECOG Performance Score	0	3526 (97.1)	107 (2.9)	-	2.63 (1.88 to 3.66)	-
	≥1	2097 (92.1)	181 (7.9)	2.71 (2.12 to 3.46)	1.65 (1.23 to 2.20)	0.001
Current smoker	No	5048 (95.5)	239 (4.5)	-	-	-
	Yes	575 (92.1)	49 (7.9)	1.73 (1.25 to 2.38)	1.32 (0.93 to 1.88)	0.119
Pre-existing respiratory condition	No	5028 (95.7)	228 (4.3)	-	-	-
	Yes	595 (90.8)	60 (9.2)	2.00 (1.48 to 2.70)	1.19 (0.86 to 1.66)	0.293
Revised Cardiac Risk Index	0	1317 (98.7)	17 (1.3)	-	-	-
	1	3170 (95.0)	167 (5.0)	3.54 (2.14 to 5.86)	1.99 (0.89 to 4.47)	0.093
	2	930 (92.8)	72 (7.2)	5.46 (3.20 to 9.31)	2.09 (0.88 to 4.95)	0.094
	≥3	206 (86.6)	32 (13.4)	10.52 (5.71 to 19.37)	3.07 (1.21 to 7.80)	0.018
Disease stage	Early stage	3839 (96.0)	161 (4.0)	-	-	-
	Advanced stage	1784 (93.4)	127 (6.6)	1.67 (1.31 to 2.12)	1.60 (1.25 to 2.07)	<0.001
Hospital type	No defined pathway	4314 (94.4)	258 (5.6)	-	-	-
	COVID-19 free surgical pathway	1309 (97.8)	30 (2.2)	0.47 (0.31 to 0.70)	0.49 (0.32 to 0.74)	0.001
Community SARS- Cov-2 risk	Low	5105 (95.3)	250 (4.7)	-	-	-
	High	518 (93.2)	38 (6.8)	1.47 (0.95 to 2.26)	1.60 (1.01 to 2.54)	0.044

Data included from 5911 patients with complete data. COVID-19=Coronavirus disease 2019. ASA=American Society of Anaesthesiologists. ECOG=Eastern Cooperative Oncology Group. Percentages calculated as a proportion of row total. Area under the Receiver Operating Characteristic curve for model: 0.79 (excellent discrimination).

Supplementary Table 6. Subgroup analysis of factors associated with postoperative pulmonary complications after minor surgery.

Factor	Level	Outcome		Unadjusted model (Odds ratio, 95% CI)	Adjusted model (Odds ratio, 95% CI)	P-value
		None (N=1822)	Pulmonary complications (N=22)			
Screening type	None	1478 (98.7)	19 (1.3)	-	-	-
	Swab only	344 (99.1)	3 (0.9)	0.68 (0.20 to 2.31)	0.58 (0.16 to 2.13)	0.413
Age	<50 years	373 (99.7)	1 (0.3)	-	-	-
	50-59 years	444 (99.1)	4 (0.9)	3.31 (0.37 to 29.77)	2.18 (0.24 to 20.19)	0.491
	60-69 years	488 (98.2)	9 (1.8)	6.77 (0.85 to 53.64)	3.23 (0.39 to 27.17)	0.280
	70-79 years	366 (98.7)	5 (1.3)	5.05 (0.59 to 43.46)	1.69 (0.17 to 16.46)	0.651
	≥80 years	151 (98.1)	3 (1.9)	7.32 (0.76 to 70.95)	1.91 (0.17 to 21.59)	0.600
Sex	Female	1352 (99.1)	12 (0.9)	-	-	-
	Male	470 (97.9)	10 (2.1)	2.46 (1.05 to 5.72)	1.32 (0.51 to 3.42)	0.571
BMI	Normal	711 (98.9)	8 (1.1)	-	-	-
	Overweight	564 (98.9)	6 (1.1)	0.94 (0.33 to 2.73)	0.84 (0.28 to 2.57)	0.766
	Obese	356 (98.6)	5 (1.4)	1.24 (0.40 to 3.82)	1.01 (0.30 to 3.41)	0.988
	Underweight	40 (100.0)	0 (0)	<i>Not estimated</i>	<i>Not estimated</i>	-
	Missing	151 (98.1)	3 (1.9)	1.70 (0.45 to 6.47)	1.65 (0.38 to 7.05)	0.502
ASA Grade	Grade 1-2	1411 (99.0)	14 (1.0)	-	-	-
	Grade 3-5	411 (98.1)	8 (1.9)	1.98 (0.82 to 4.75)	0.68 (0.22 to 2.11)	0.509
Specialty	Abdominal	312 (99.0)	3 (1.0)	-	-	-
	Thoracic or thoracoabdominal	5 (83.3)	1 (16.7)	21.20 (1.87 to 240.67)	33.78 (2.27 to 503.51)	0.011
	Other	1505 (98.8)	18 (1.2)	1.24 (0.36 to 4.25)	3.68 (0.89 to 15.15)	0.071
ECOG Performance Score	0	1273 (99.4)	8 (0.6)	-	-	-
	≥1	549 (97.5)	14 (2.5)	4.05 (1.69 to 9.71)	3.57 (1.28 to 9.90)	0.015
Current smoker	No	1596 (98.9)	18 (1.1)	-	-	-
	Yes	226 (98.3)	4 (1.7)	1.59 (0.53 to 4.75)	1.47 (0.43 to 4.95)	0.538
Pre-existing respiratory condition	No	1634 (98.9)	18 (1.1)	-	-	-
	Yes	188 (97.9)	4 (2.1)	1.97 (0.66 to 5.89)	1.64 (0.50 to 5.34)	0.412
Revised Cardiac Risk Index	0	1219 (99.2)	10 (0.8)	-	-	-
	1	469 (98.5)	7 (1.5)	1.82 (0.69 to 4.81)	2.05 (0.65 to 6.52)	0.222
	2	109 (97.3)	3 (2.7)	3.39 (0.92 to 12.50)	3.45 (0.70 to 17.01)	0.128
	≥3	25 (92.6)	2 (7.4)	9.94 (2.07 to 47.75)	10.88 (1.55 to 76.57)	0.017
Disease stage	Early stage	1545 (99.0)	15 (1.0)	-	-	-
	Advanced stage	277 (97.5)	7 (2.5)	2.58 (1.04 to 6.39)	2.35 (0.86 to 6.38)	0.094
Hospital type	No defined pathway	1359 (98.6)	19 (1.4)	-	-	-
	COVID-19 free surgical pathway	463 (99.4)	3 (0.6)	0.47 (0.14 to 1.59)	0.44 (0.12 to 1.60)	0.211
Community SARS-Cov-2 risk	Low	1616 (98.8)	19 (1.2)	-	-	-
	High	206 (98.6)	3 (1.4)	1.26 (0.37 to 4.29)	1.80 (0.49 to 6.70)	0.378

Data included from 1844 patients with complete data. COVID-19=Coronavirus disease 2019. ASA=American Society of Anaesthesiologists. ECOG=Eastern Cooperative Oncology Group. Percentages calculated as a proportion of row total. Area under the Receiver Operating Characteristic curve for model: 0.84 (excellent discrimination).

Supplementary Table 7. Sensitivity analysis of factors associated with postoperative pulmonary complications with exclusion of potentially missing data for the primary outcome measure

Factor	Level	Outcome		Unadjusted model (Odds ratio, 95% CI)	Adjusted model (Odds ratio, 95% CI)	P-value
		None (N=8173)	Pulmonary Complications (N=342)			
Screening type	None	5984 (95.7)	270 (4.3)	-	-	-
	CT only	494 (95.4)	24 (4.6)	1.20 (0.76 to 1.88)	1.26 (0.78 to 2.03)	0.353
	Swab only	1389 (97.2)	40 (2.8)	0.67 (0.48 to 0.97)	0.68 (0.47 to 0.99)	0.044
	Swab + CT	306 (97.5)	8 (2.5)	0.63 (0.30 to 1.30)	0.56 (0.27 to 1.18)	0.128
Age	<50 years	1530 (98.8)	19 (1.2)	-	-	-
	50-59 years	1772 (97.6)	44 (2.4)	2.08 (1.23 to 3.51)	1.33 (0.76 to 2.33)	0.313
	60-69 years	2256 (95.6)	104 (4.4)	3.79 (2.34 to 6.13)	1.80 (1.07 to 3.01)	0.026
	70-79 years	1956 (93.8)	130 (6.2)	5.36 (3.32 to 8.63)	2.00 (1.19 to 3.38)	0.009
	≥80 years	659 (93.6)	45 (6.4)	5.43 (3.19 to 9.25)	1.94 (1.07 to 3.52)	0.028
Sex	Female	5091 (98.0)	106 (2.0)	-	-	-
	Male	3082 (92.9)	236 (7.1)	3.53 (2.82 to 4.41)	2.28 (1.78 to 2.92)	<0.001
BMI	Normal	3207 (96.4)	121 (3.6)	-	-	-
	Overweight	2587 (96.2)	102 (3.8)	1.09 (0.84 to 1.40)	0.90 (0.68 to 1.19)	0.446
	Obese	1724 (95.8)	76 (4.2)	1.18 (0.89 to 1.56)	0.92 (0.67 to 1.26)	0.613
	Underweight	194 (95.1)	10 (4.9)	1.24 (0.64 to 2.41)	1.29 (0.64 to 2.59)	0.479
	Missing	461 (93.3)	33 (6.7)	1.47 (1.00 to 2.16)	1.62 (1.04 to 2.50)	0.031
ASA Grade	Grade 1-2	5990 (97.3)	168 (2.7)	-	-	-
	Grade 3-5	2183 (92.6)	174 (7.4)	2.87 (2.32 to 3.55)	1.41 (1.08 to 1.84)	0.012
Specialty	Abdominal	4421 (95.4)	212 (4.6)	-	-	-
	Thoracic or thoracoabdominal	527 (86.8)	80 (13.2)	2.71 (2.06 to 3.56)	2.70 (1.98 to 3.68)	<0.001
	Other	3225 (98.5)	50 (1.5)	0.33 (0.24 to 0.44)	1.22 (0.73 to 2.02)	0.451
ECOG Performance Score	0	5288 (97.6)	128 (2.4)	-	-	-
	≥1	2885 (93.1)	214 (6.9)	2.84 (2.29 to 3.51)	1.78 (1.37 to 2.32)	<0.001
Current smoker	No	7301 (96.3)	283 (3.7)	-	-	-
	Yes	872 (93.7)	59 (6.3)	1.58 (1.20 to 2.10)	1.33 (0.97 to 1.83)	0.077
Pre-existing respiratory condition	No	7313 (96.4)	274 (3.6)	-	-	-
	Yes	860 (92.7)	68 (7.3)	2.04 (1.57 to 2.65)	1.13 (0.84 to 1.54)	0.418
RCRI	0	2683 (98.9)	29 (1.1)	-	-	-
	1	4092 (95.5)	195 (4.5)	4.06 (2.80 to 5.90)	2.11 (1.16 to 3.83)	0.014
	2	1147 (93.5)	80 (6.5)	6.08 (4.04 to 9.16)	2.19 (1.13 to 4.22)	0.020
	≥3	251 (86.9)	38 (13.1)	12.61 (7.79 to 20.40)	3.68 (1.77 to 7.64)	<0.001
Operation grade	Minor	1932 (98.8)	23 (1.2)	-	-	-
	Major	6241 (95.1)	319 (4.9)	4.02 (2.71 to 5.98)	2.19 (1.35 to 3.54)	0.001
Disease stage	Early stage	5857 (96.8)	194 (3.2)	-	-	-
	Advanced stage	2316 (94.0)	148 (6.0)	1.84 (1.49 to 2.27)	1.61 (1.28 to 2.03)	<0.001
Hospital type	No defined pathway	5928 (95.2)	300 (4.8)	-	-	-
	COVID-19 free surgical pathway	2245 (98.2)	42 (1.8)	0.48 (0.35 to 0.66)	0.45 (0.31 to 0.65)	<0.001
Community SARS- Cov-2 risk	Low	7154 (96.0)	298 (4.0)	-	-	-
	High	1019 (95.9)	44 (4.1)	1.05 (0.72 to 1.52)	1.38 (0.90 to 2.12)	0.139

When recording postoperative complications on the REDCap database, investigators were able to select a tick-box to indicate that a specific complication had occurred within 30-days of surgery. A second tick-box was available to confirm the absence of complications where no complications were recorded. For the purpose of the main model, patients with no tick-box selected were analysed as having no pulmonary complications. A sensitivity analysis was completed where patients were excluded when no complication was selected, and the absence of complications was not confirmed (n=83, 0.9%). There were no changes to directions of effect and/or significance of effect. Data included from 8515 patients with complete data. COVID-19=Coronavirus disease 2019. ASA=American Society of Anaesthesiologists. RCRI= Revised Cardiac Risk Index. ECOG=Eastern Cooperative Oncology Group. Percentages calculated as a proportion of row total. Area under the Receiver Operating Characteristic curve for model: 0.80 (excellent discrimination).

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