

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

COVIDSurg Collaborative\*

Members of the COVIDSurg Collaborative are co-authors of this study and are listed in *Appendix S1*

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## Abstract

**Background:** 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:** This international cohort study included adult patients undergoing elective surgery for cancer in areas affected by SARS-CoV-2 up to 19 April 2020. Patients suspected of SARS-CoV-2 infection before operation 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 per cent) underwent preoperative testing: 1458 (16.6 per cent) had a swab test, 521 (5.9 per cent) CT only, and 324 (3.7 per cent) swab and CT. Pulmonary complications occurred in 3.9 per cent, whereas SARS-CoV-2 infection was confirmed in 2.6 per cent. After risk adjustment, having at least one negative preoperative nasopharyngeal swab test (adjusted odds ratio 0.68, 95 per cent confidence interval 0.68 to 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, the number needed to swab test before major or minor surgery was 18 and 48 respectively in high-risk areas, and 73 and 387 in low-risk areas.

**Conclusion:** 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<sup>1</sup>. 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<sup>2</sup>. Once established, a SARS-CoV-2 postoperative pulmonary complication was associated with a 23.8 per cent mortality rate, compared with a rate of 2 per cent without SARS-CoV-2<sup>3</sup>. Because of this, restarting elective surgery has proved challenging, with many millions more operations being postponed every month.

Healthcare providers have continued some time-dependent surgery (such as operations 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 optimize

outcomes by identifying presymptomatic 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<sup>4–6</sup>. The mainstay of testing is nasopharyngeal swab test with quantitative reverse transcriptase-PCR (RT-qPCR) to detect SARS-CoV-2 viral RNA<sup>7,8</sup>, although preoperative CT has also been suggested, especially before major surgery<sup>9</sup>.

To support the global implementation of testing before elective surgery, better evidence is needed to support its role and to identify patients who 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 assessment of 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

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

## Methods

This was an international multicentre cohort study of adults undergoing elective cancer surgery in areas affected by the SARS-CoV-2 pandemic who 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<sup>10</sup>. The study protocol was registered at ClinicalTrials.gov (NCT04384926) and has been reported in detail previously<sup>11</sup>.

## 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 for up to 30 days from the day of surgery (day 0).

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 thoracic CT in the 7 days before surgery) were excluded from this study. This study therefore included only patients who were not suspected of having SARS-CoV-2 at the time of surgery. Data were not collected on patients who 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 patient infected with SARS-CoV-2 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 included in this analysis: swab test, defined as nasopharyngeal swab and identification of viral RNA by RT-qPCR, according to local protocols; imaging by thoracic CT only; swab test and CT; and no test. The timing of swab testing was categorized as: single swab test on day 4–7 before operation; single swab test on day 1–3 before operation; or repeat swab, defined as one or more swabs on day 1–3 and day 4–7 before surgery.

## 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, 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 by a positive swab test, thoracic CT, or clinical diagnosis of symptomatic COVID-19 in patients for whom a swab test and CT 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 patient's preoperative health and functional status was summarized using age, sex, BMI, respiratory condition, Revised Cardiac Risk Index score, and ASA fitness 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 stage (organ-confined, non-nodal, non-metastatic, fully resectable) or advanced stage (growth beyond organ, nodal, metastatic operated with curative intent). Grade of surgery was assigned based on the Clinical Coding & Schedule Development Group classification<sup>12</sup> 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 in each participating hospital's local community was extracted from WHO<sup>13</sup>, European Centre for Disease Prevention and Control<sup>14</sup>, or US Centers for Disease Control and Prevention statistics. Hospitals were classified as being in communities with either a low (fewer than 25 cases per 100 000 population) or high (25 or more 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<sup>11</sup>. Patients were considered to have been treated within a COVID-19-free pathway if there was a policy of complete segregation from patients with COVID-19 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<sup>15,16</sup>. In the present study, low-volume centres (fewer than 5 patients per specialty group) were identified, and reviewed independently 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 STROBE<sup>17</sup> and reported according to SAMPL<sup>18</sup> guidelines. Missing data were recorded in summary tables where applicable. The  $\chi^2$  test was used for analysis of categorical data.

Hierarchical, multilevel univariable and multivariable logistic regression models were used to examine associations between preoperative testing strategy and the primary outcome measure, summarized as adjusted odds ratios (ORs) with 95 per cent confidence intervals. 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 who need to be tested to prevent an additional pulmonary complication. As the mainstay of current testing protocols, it was predicted that the most common preoperative test would be nasopharyngeal swab test. It was planned to explore the impact of swab tests on two key

subgroups: high versus low SARS-CoV-2 risk, and major versus minor operations.

Analyses were carried out using the R version 3.1.1 (packages *finalfit*, *tidyverse* and *ggplot2*) (R Foundation for Statistical Computing, Vienna, Austria).

## Results

Of 9171 patients included in this study, 8784 (95.8 per cent) had data available on preoperative testing and were included in the analysis. Operations were performed in 432 hospitals from 53 countries, of which 6746 (76.8 per cent) were major, and 1087 (12.4 per cent) were performed in high SARS-CoV-2 risk areas. A full list of included operations grouped by preoperative testing strategy is shown in [Table S1](#).

### Preoperative testing strategies

Overall, 2303 of 8784 patients (26.2 per cent) underwent preoperative testing. This included 1458 (16.6 per cent) who had a swab test, 521 (5.9 per cent) who had CT only, and 324 (3.7 per cent) who had a swab and CT. There was significant variation in the proportion of patients who underwent testing at country level ([Fig. 1](#)). The overall proportion of patients tested increased over the study period ([Fig. S1](#)).

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 with a higher performance score or advanced cancer) were more likely to have a swab test than no test. Of 1458 patients who had swab testing, 164 (11.2 per cent) were tested on preoperative day 4–7, 1213 (83.2 per cent) had a single swab on preoperative day 1–3, and just 63 (4.3 per

cent) had repeat swabs. The groups undergoing CT either alone or with a swab test more commonly underwent thoracic or thoracoabdominal surgery, or had advanced disease.

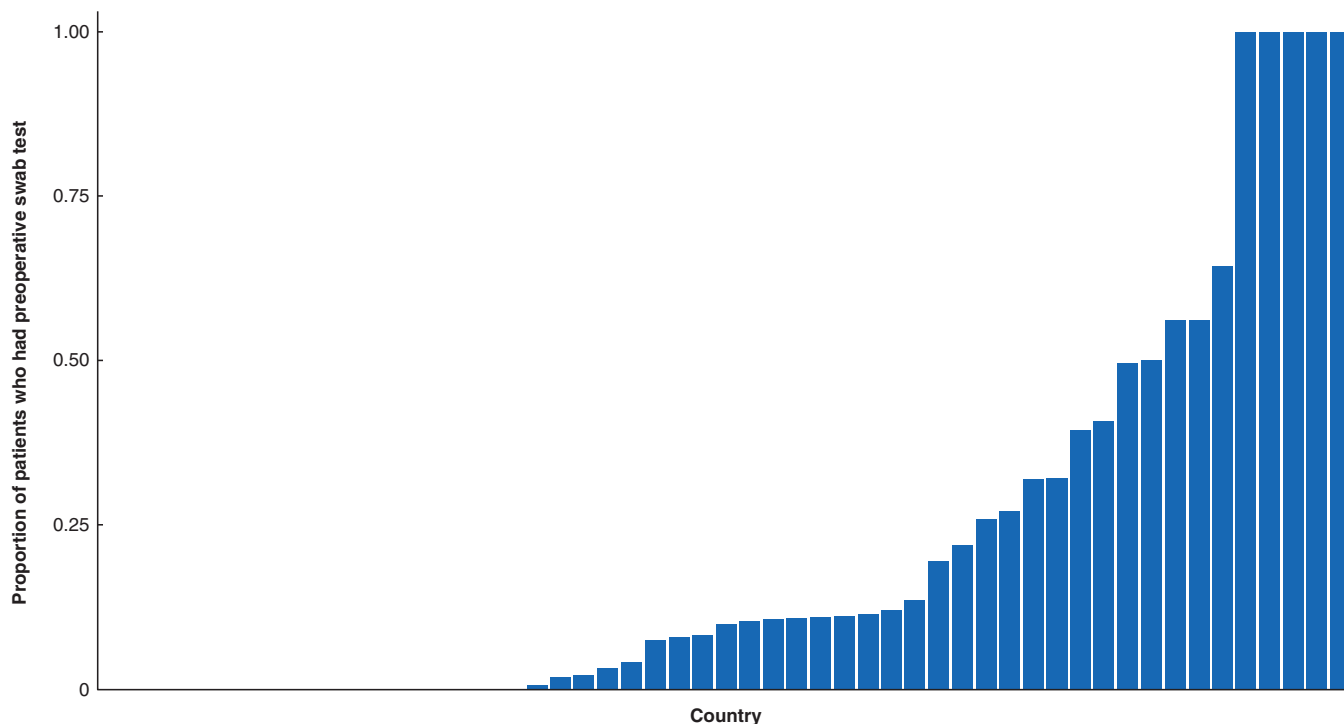
### Pulmonary complications

The overall postoperative pulmonary complication rate was 3.9 per cent (346 of 8784). This was higher in patients who had no test (4.2 per cent, 272 of 6481) or CT only (4.8 per cent, 25 of 521) than in those who had a swab test (2.8 per cent, 41 of 1458), or swab and CT (2.5 per cent, 8 of 324) ( $P=0.031$ ). After adjustment, a swab test was associated with reduced pulmonary complications (adjusted OR 0.68, 95 per cent c.i. 0.47 to 0.98,  $P=0.040$ ) ([Table S2](#)); CT only, or swab and CT were not ([Fig. 2](#)). This was consistent in a sensitivity analysis with potentially missing data excluded ([Table S7](#)). There was no additional benefit from repeat swab testing beyond a single swab on preoperative day 1–3 ([Table 2](#)).

### Subgroup analyses

Swab testing was associated with a reduction in pulmonary complications in high-risk areas (adjusted OR 0.25, 95 per cent c.i. 0.09 to 0.76;  $P=0.014$ ) ([Table S3](#)), but not in low-risk areas (adjusted OR 0.72, 0.48 to 1.08,  $P=0.108$ ) ([Table S4](#)). Swab testing was associated with a reduction in pulmonary complications after major surgery (adjusted OR 0.63, 0.42 to 0.93;  $P=0.019$ ) ([Table S5](#)), but not after minor surgery (adjusted OR 0.58, 0.16 to 2.13;  $P=0.413$ ) ([Table S6](#)). A summary of subgroup models is shown in [Fig. 3](#).

The 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.



**Fig. 1** Variation in preoperative swab testing rates across included countries

Each bar represents one country. Contributing countries were anonymized in accordance with the study protocol. Swab, nasopharyngeal swab and identification of viral RNA by reverse transcriptase–quantitative PCR, according to local protocols, with or without addition of thoracic CT.

**Table 1.** Comparison of patients by type of preoperative testing

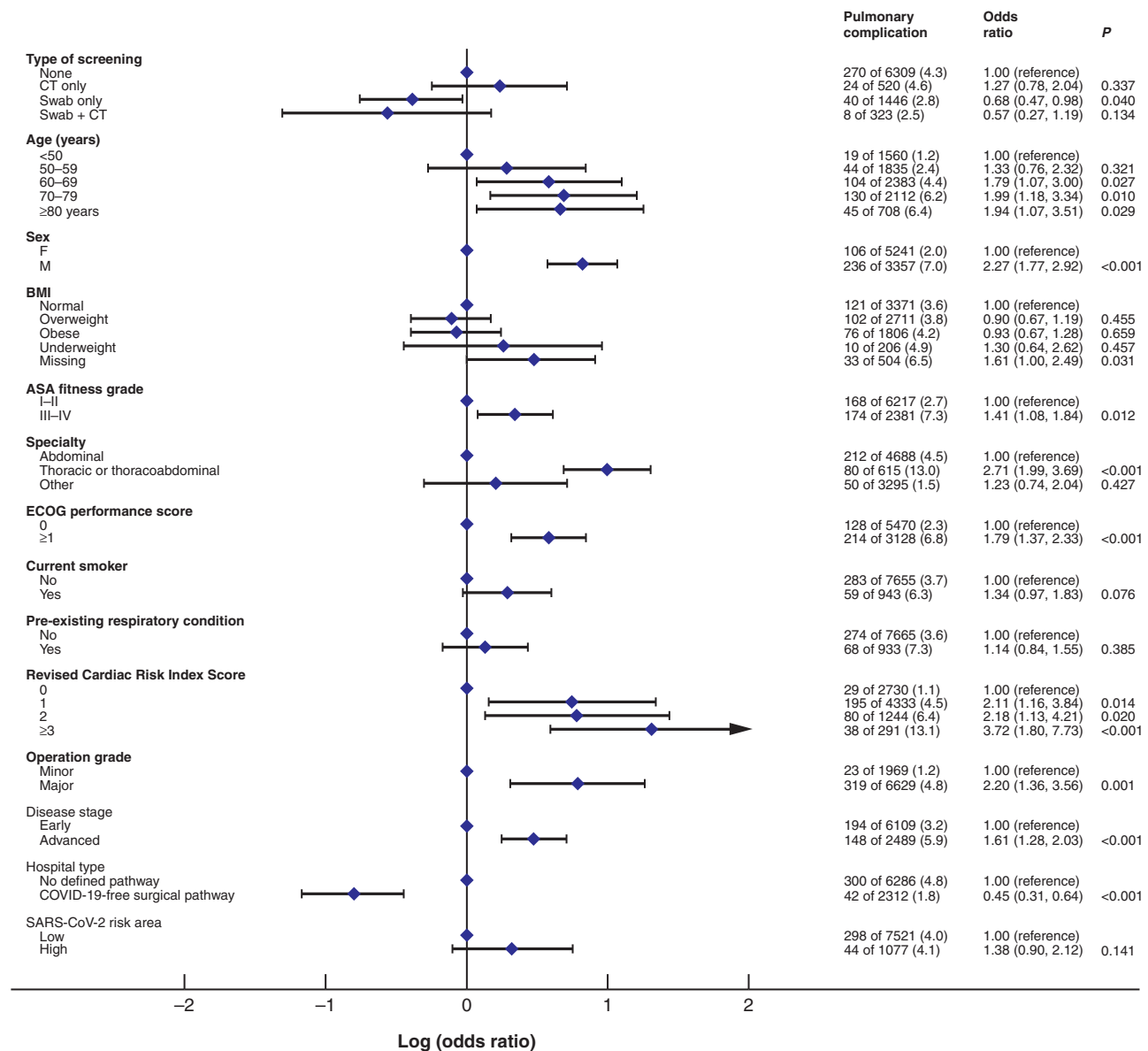
|                                  | No test (n=6481) | Swab only (n=1458) | CT only (n=521) | Swab + CT (n=324) | P*      |
|----------------------------------|------------------|--------------------|-----------------|-------------------|---------|
| Age (years)                      |                  |                    |                 |                   | 0.069   |
| < 50                             | 1212 (18.7)      | 227 (15.6)         | 95 (18.2)       | 52 (16.0)         |         |
| 50–59                            | 1393 (21.5)      | 296 (20.3)         | 120 (23.0)      | 84 (25.9)         |         |
| 60–69                            | 1786 (27.6)      | 413 (28.3)         | 140 (26.9)      | 93 (28.7)         |         |
| 70–79                            | 1571 (24.2)      | 381 (26.1)         | 128 (24.6)      | 73 (22.5)         |         |
| ≥ 80                             | 519 (8.0)        | 141 (9.7)          | 38 (7.3)        | 22 (6.8)          |         |
| Sex                              |                  |                    |                 |                   | 0.056   |
| Female                           | 4000 (61.7)      | 844 (57.9)         | 320 (61.4)      | 195 (60.2)        |         |
| Male                             | 2479 (38.3)      | 614 (42.1)         | 201 (38.6)      | 129 (39.8)        |         |
| Missing                          | 2                | 0                  | 0               | 0                 |         |
| BMI                              |                  |                    |                 |                   | < 0.001 |
| Normal                           | 2406 (40.4)      | 665 (46.4)         | 227 (44.6)      | 114 (35.5)        |         |
| Overweight                       | 1974 (33.2)      | 467 (32.6)         | 184 (36.1)      | 123 (38.3)        |         |
| Obese                            | 1421 (23.9)      | 262 (18.3)         | 83 (16.3)       | 75 (23.4)         |         |
| Underweight                      | 149 (2.5)        | 38 (2.7)           | 15 (2.9)        | 9 (2.8)           |         |
| Missing                          | 531              | 26                 | 12              | 3                 |         |
| ASA fitness grade                |                  |                    |                 |                   | < 0.001 |
| I–II                             | 4655 (72.2)      | 999 (68.5)         | 412 (79.2)      | 257 (79.3)        |         |
| III–V                            | 1792 (27.8)      | 459 (31.5)         | 108 (20.8)      | 67 (20.7)         |         |
| Missing                          | 34               | 0                  | 1               | 0                 |         |
| Revised Cardiac Risk Index score |                  |                    |                 |                   | < 0.001 |
| 0                                | 2147 (33.1)      | 482 (33.1)         | 125 (24.0)      | 43 (13.3)         |         |
| 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)          |         |
| Respiratory co-morbidity         |                  |                    |                 |                   | 0.915   |
| No                               | 5771 (89.0)      | 1302 (89.3)        | 469 (90.0)      | 289 (89.2)        |         |
| Yes                              | 710 (11.0)       | 156 (10.7)         | 52 (10.0)       | 35 (10.8)         |         |
| ECOG performance score           |                  |                    |                 |                   | < 0.001 |
| 0                                | 4115 (64.7)      | 842 (58.1)         | 338 (64.9)      | 220 (67.9)        |         |
| ≥ 1                              | 2247 (35.3)      | 606 (41.9)         | 183 (35.1)      | 104 (32.1)        |         |
| Missing                          | 119              | 10                 | 0               | 0                 |         |
| Cancer type                      |                  |                    |                 |                   | < 0.001 |
| Abdominal                        | 3430 (52.9)      | 784 (53.8)         | 327 (62.8)      | 238 (73.5)        |         |
| 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                    |                  |                    |                 |                   | < 0.001 |
| Early                            | 4664 (72.0)      | 1029 (70.6)        | 356 (68.3)      | 193 (59.8)        |         |
| Advanced                         | 1814 (28.0)      | 429 (29.4)         | 165 (31.7)      | 130 (40.2)        |         |
| Missing                          | 3                | 0                  | 0               | 1                 |         |
| Anaesthetic                      |                  |                    |                 |                   | < 0.001 |
| General                          | 6137 (94.7)      | 1365 (93.6)        | 510 (97.9)      | 316 (97.5)        |         |
| Regional/local                   | 344 (5.3)        | 93 (6.4)           | 11 (2.1)        | 8 (2.5)           |         |
| Operation grade                  |                  |                    |                 |                   | < 0.001 |
| Minor                            | 1529 (23.7)      | 349 (24.0)         | 90 (17.3)       | 37 (11.4)         |         |
| Major                            | 4921 (76.3)      | 1107 (76.0)        | 431 (82.7)      | 287 (88.6)        |         |
| Missing                          | 31               | 2                  | 0               | 0                 |         |
| Hospital type                    |                  |                    |                 |                   | < 0.001 |
| No defined pathway               | 5033 (77.7)      | 1070 (73.4)        | 217 (41.7)      | 120 (37.0)        |         |
| COVID-19-free surgical pathway   | 1447 (22.3)      | 388 (26.6)         | 304 (58.3)      | 204 (63.0)        |         |
| Community SARS-CoV-2 risk        |                  |                    |                 |                   | < 0.001 |
| Low                              | 5907 (91.1)      | 1258 (86.3)        | 331 (63.5)      | 201 (62.0)        |         |
| High                             | 575 (8.9)        | 200 (13.7)         | 190 (36.5)      | 123 (38.0)        |         |

Values in parentheses are percentages. CT, imaging by thoracic CT; ECOG, Eastern Cooperative Oncology Group. \* $\chi^2$  test.

### Postoperative detection of SARS-CoV-2 and mortality

SARS-CoV-2 infection and mortality rates by preoperative testing strategy are reported in [Table 4](#). The unadjusted rate of SARS-CoV-2 was lower in all groups that were tested before surgery

than among those who were not tested ( $P < 0.001$ ). The difference was greatest between swab test only (0.5 per cent, 7 of 1458) and no test (3.2 per cent, 209 of 6481). The mortality rate was lower in the group that had swab tests (0.8 per cent, 12 of 1458) or swab test and CT (0.6 per cent, 2 of 324) than in patients who were not



**Fig. 2** Factors associated with postoperative pulmonary complications in the mixed-effects model.

Values in parentheses are \*percentages and †95 per cent confidence intervals. The rate of missing data for variables included in the model was less than 1 per cent, except for BMI (6 per cent), where 'missing' was included as an additional factor level. Area under the receiver operating characteristic curve for model is 0.81 (excellent discrimination). CT, imaging by thoracic CT; ECOG, Eastern Cooperative Oncology Group.

tested (1.6 per cent, 104 of 6841), although this was not statistically significant ( $P=0.072$ ).

## Discussion

In this study, 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 from the addition of preoperative thoracic CT or repeat swabs. The results allow the authors 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 areas. The NNT values presented for these groups provide evidence to support implementation by health-care providers, based on locally available resources.

The beneficial effect of swab testing was likely to result from identification of presymptomatic or asymptomatic patients before admission, who could then have surgery delayed. This effect is mediated by two mechanisms. First, it stops presymptomatic patients developing severe, symptomatic disease (COVID-19) after operation. Second, it prevents cross-infection from asymptomatic patients to other patients scheduled for elective surgery on 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<sup>11</sup>.

**Table 2.** Univariable and multivariable logistic regression analyses of association between timing and number of preoperative swab tests and postoperative pulmonary complications

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

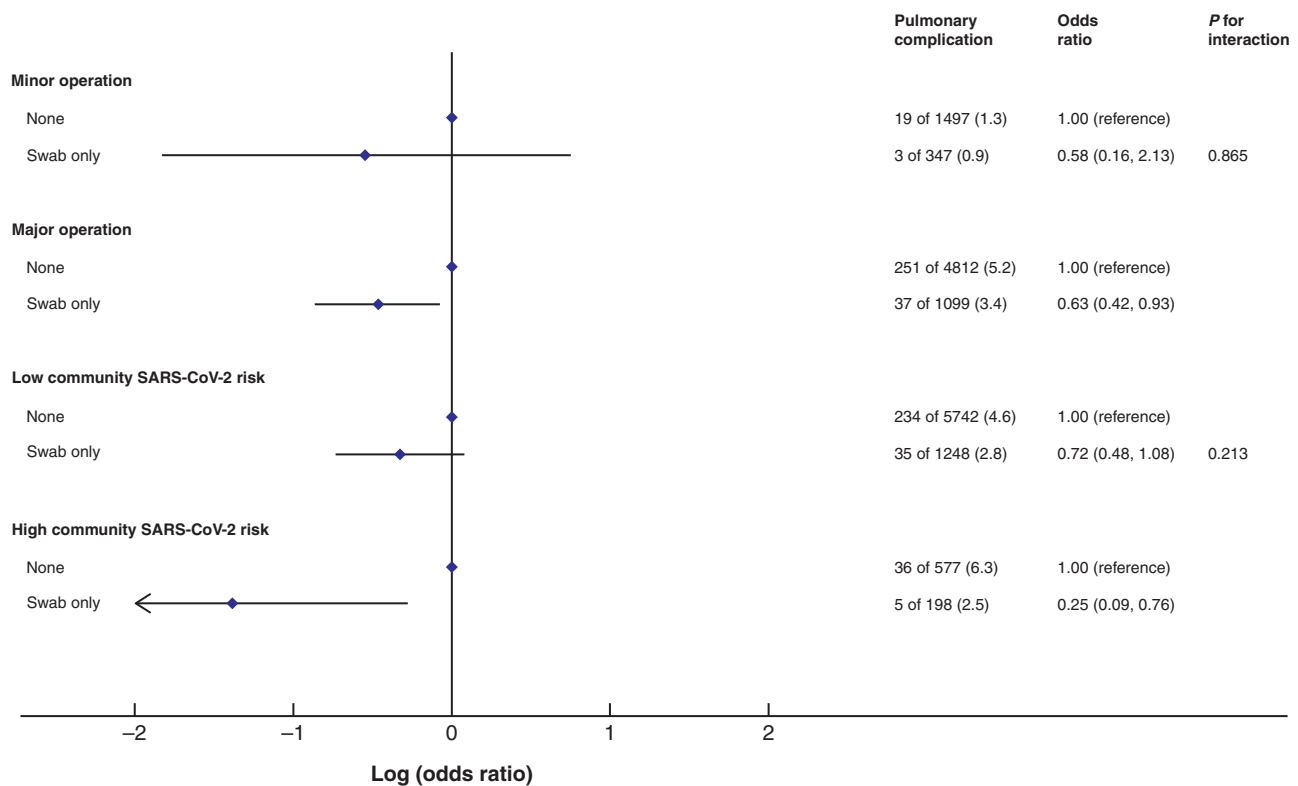
Values in parentheses are 95 per cent confidence intervals. Data from 6217 patients with complete data were included in the analysis.

\*One or more swabs on day 1–3 and day 4–7 before surgery. CT, imaging by thoracic CT; ECOG, Eastern Cooperative Oncology Group. Area under the receiver operating characteristic curve for model is 0.80 (excellent discrimination).

This study did not aim to evaluate the diagnostic accuracy of swab testing, which has been explored in detail elsewhere<sup>7,8,19,20</sup>. Although the present data did not show a clear benefit to repeat swab testing, only a small group of patients 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 per cent c.i. 68.1 to 78.0) per cent<sup>20</sup>. For those identified to be at highest baseline risk of pulmonary complications and/or SARS-CoV-2 infection, for example older patients, those with worse functional status, or those undergoing thoracoabdominal

surgery, there may still be a role for selective repeat swabbing. As understanding of the diagnostic accuracy of SARS-CoV-2 tests evolves over time, new testing strategies (such as 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 standardization of swab testing worldwide. The reasons for this variation need to be better understood, including relationships with health system resourcing and policy<sup>4,5</sup>. In the present data, the testing rate increased over time from less



**Fig. 3** Summary of subgroup analyses of swab testing in different patient populations

Values in parentheses are \*percentages and †95 per cent confidence intervals. Grade of surgery was assigned based on the Clinical Coding & Schedule Development Group categories 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 (fewer than 25 cases per 100 000 population) or high (25 or more cases per 100 000 population).

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

|                               | Pulmonary complications |                 | Adjusted ARR (%) | NNT |
|-------------------------------|-------------------------|-----------------|------------------|-----|
|                               | No test                 | Swab test       |                  |     |
| Major surgery, high-risk area | 33 of 429 (7.7)         | 5 of 134 (3.7)  | 5.67             | 18  |
| Minor surgery, high-risk area | 3 of 144 (2.1)          | 0 of 66 (0)     | 2.10*            | 48  |
| Major surgery, low-risk area  | 219 of 4492 (4.9)       | 33 of 973 (3.4) | 1.37             | 73  |
| Minor surgery, low-risk area  | 16 of 1385 (1.2)        | 3 of 283 (1.1)  | 0.26             | 387 |

Values in parentheses are percentages.

\*Estimate from unadjusted model as model adjustment not possible. ARR, absolute risk reduction; NNT, number needed to test, rounded up to nearest whole person. Grade of surgery was assigned based on the Clinical Coding & Schedule Development Group categories 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 (fewer than 25 cases per 100 000 population) or high (25 or more cases per 100 000 population).

than 10 per cent at the end of February, to almost 40 per cent in the middle of April 2020. Although this indicates a growing uptake of preoperative swab testing internationally, implementation remained incomplete, with 18 countries reporting a testing rate of zero. Care providers should now upscale the provision of routine preoperative testing to provide safe elective surgery during the pandemic.

CT remains controversial as it is resource-intensive and its validity in detection of COVID-19 has not been demonstrated, despite proposed scoring systems<sup>21–23</sup>. A systematic review<sup>23</sup> of diagnostic accuracy studies failed to demonstrate the accuracy of

thoracic CT as a screening tool in asymptomatic patients. In the present study, CT was used more commonly in groups undergoing thoracoabdominal surgery and those with advanced disease. There may be a selective role for dual-purpose imaging before surgery that can both restage disease after a delay to surgery, and identify characteristic changes of COVID-19. This study showed no additional benefit to performing CT in addition to a single swab test, meaning that the additional cost and organizational burden of CT as a screening test in asymptomatic patients is unlikely to be justified. This corroborates the findings of a multicentre study of 2093 patients undergoing surgery in the

**Table 4.** Unadjusted outcomes by type of preoperative testing

|                         | No test (n = 6481) | Swab only (n = 1458) | CT only (n = 521) | Swab + CT (n = 324) | P*      |
|-------------------------|--------------------|----------------------|-------------------|---------------------|---------|
| Pulmonary complications |                    |                      |                   |                     | 0.031   |
| No                      | 6209 (95.8)        | 1417 (97.2)          | 496 (95.2)        | 316 (97.5)          |         |
| Yes                     | 272 (4.2)          | 41 (2.8)             | 25 (4.8)          | 8 (2.5)             |         |
| SARS-CoV-2 infection    |                    |                      |                   |                     | < 0.001 |
| No                      | 6345 (98.4)        | 1451 (99.5)          | 516 (99.0)        | 319 (98.5)          |         |
| Yes                     | 209 (3.2)          | 7 (0.5)              | 5 (1.0)           | 5 (1.5)             |         |
| Mortality               |                    |                      |                   |                     | 0.072   |
| No                      | 6272 (98.4)        | 1437 (99.2)          | 514 (98.8)        | 315 (99.4)          |         |
| Yes                     | 104 (1.6)          | 12 (0.8)             | 6 (1.2)           | 2 (0.6)             |         |
| Missing                 | 105                | 9                    | 1                 | 7                   |         |

Values in parentheses are percentages. CT, imaging by thoracic CT.  
\* $\chi^2$  test.

Netherlands, in which the incremental yield of thoracic CT in asymptomatic patients was slight, at 0.4 per cent<sup>9</sup>. Similarly, in a small series<sup>22</sup>, high-resolution CT chest added very little additional value and a high resource cost, with just 3 of 386 patients with a negative swab who had thoracic CT having surgery postponed.

There were limitations to this study. First, its observational nature may have left a residual risk of selection bias, despite use of 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 influenced the effect observed. Second, some of the subgroup sizes were small (for example CT, repeat swab test), meaning there were risks of type II errors. Third, 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 restarts and upscaling. In some instances, this may need to be done with caution, owing 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 who were not suspected of having COVID-19 before elective surgery. It was not designed to test the diagnostic accuracy of different testing protocols.

The strengths of this study lie in the large number of patients, a pansurgical 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 organizationally challenging. Urgent research is also needed to identify the optimum delay to surgery for patients who have a positive swab test. Symptom questionnaires or clinical assessment were not evaluated as a method of identifying patients infected with SARS-CoV-2. Although these may prove effective in identifying some subtly symptomatic patients, they are currently not standardized and reproducibility is therefore uncertain.

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## Supplementary material

Supplementary material is available at *BJS* online.

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