BMJ Open

Perioperative SARS-CoV-2 infection and postoperative complications: a single-centre retrospective cohort study in China

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To cite: Zhan J, Zhong F, Dai L, *et al*. Perioperative SARS-CoV-2 infection and postoperative complications: a single-centre retrospective cohort study in China. *BMJ Open* 2025;**15**:e093044. doi:10.1136/bmjopen-2024-093044

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (https://doi.org/10.1136/bmjopen-2024-093044).

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Received 29 August 2024
Accepted 15 April 2025

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ABSTRACT

Objective To explore the association between perioperative SARS-CoV-2 infection and the postoperative complications during the breakout of the Omicron epidemic wave.

Design Observational retrospective cohort study. Multivariable logistic regression was performed to explore the association between the duration from surgery to COVID-19 diagnosis and the likelihood of postoperative complications.

Setting A general hospital in China.

Participants 7927 patients aged 18 years and older who underwent surgical treatment between 1 December 2022 and 28 February 2023.

Primary outcome measures The outcome was a composite of postoperative adverse events that occurred within the initial 30 postoperative days.

Results Of all patients, 420 (11.76%) experienced postoperative complications. Compared with No COVID-19, preoperative COVID-19 within 1 week (pre-1w) exhibited a high risk of postoperative complications (adjusted OR (aOR), 2.67; 95% CI 1.50 to 4.78), followed by patients with pre-2w (aOR, 2.14; 95% CI 1.20 to 3.80). For patients with postoperative COVID-19 within 1 week (post-1w), the aOR was 2.48 (95% CI 1.48 to 4.13), followed by patients with post-2w (aOR 1.95; 95% CI 1.10 to 3.45), and those with post-3w (aOR 2.25; 95% CI 1.27 to 3.98). The risks of postoperative complications decreased roughly with the increase of the time interval between the surgery date and SARS-CoV-2 infection. Stratification analyses suggested that perioperative COVID-19 increased the risk of postoperative complications in older patients, smokers, those with comorbidities or experiencing moderate or severe COVID-19 symptoms.

Conclusions Our findings reveal a significant time-dependent relationship between perioperative COVID-19 and postoperative complications, highlighting the importance of tailored preoperative risk evaluations, enhanced postoperative surveillance, and the implementation of effective postoperative COVID-19 prevention measures.

Trial registration number ChiCTR2300072473.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study captured both preoperative and postoperative SARS-CoV-2 infections, providing recommendations for optimising surgical timing and improving postoperative management.
⇒ A broad range of surgical complications was considered, enabling physicians to gain a comprehensive understanding of the overall perioperative risk.
⇒ Both infected and uninfected patients have a COVID-19 PCR or antigen testing result, ensuring the reliability of the findings.
⇒ A single-centre retrospective observational design of the study limited the generalisability of the results. (1)

INTRODUCTION

Since the first reports of a novel SARS-CoV-2 in December 2019 in Wuhan, China, the SARS-CoV-2 virus has evolved five variants from Alpha to Omicron.[1–3] This has led to a rapid spread, both regionally and globally, resulting in over 760 million cases and 6.9 million deaths worldwide.[4] Perioperative COVID-19 has been demonstrated to have an adverse impact on perioperative mortality and morbidity.[5–9] Approximately 50% of SARS-CoV-2-infected individuals experience postoperative pulmonary complications, and the overall 30-day mortality was up to 23.8%.[9] To mitigate the postoperative risks, a large number of surgeries had been postponed. While this may delay the treatment of their primary diseases and decrease survival.[10–13] Hence, there is a crucial need for a comprehensive assessment of the health advantages associated with the postponement of surgical management and the potential adverse repercussions of delayed treatment.

Emerging in November 2021, the SARS-CoV-2 Omicron variant became the dominant variant and exhibited increased transmissibility while inducing less severe disease compared with previous variants.[14–18] In addition, massive vaccination programmes and the use of antiviral treatments have changed the clinical characteristics of patients with COVID-19.[19–23] The current evidence regarding postoperative outcomes in patients undergoing surgery during the Omicron wave was inconsistent. Two studies found an increased postoperative risk when surgeries were performed within 1 week after contracting COVID-19.[24 25] On the contrary, other studies found no significant difference in postoperative outcomes comparing patients with SARS-CoV-2 Omicron infection with those who were not infected.[26 27] Furthermore, few studies focused on the risk of postoperative complications associated with SARS-CoV-2 infection after surgery.

Given the rapid global spread and significant impact of COVID-19, coupled with its high mutation rate, current research findings on postoperative complications associated with COVID-19 infection remain inconsistent. In this study, we aimed to investigate the associations between preoperative or postoperative SARS-CoV-2 infection and postoperative outcomes, respectively. We further analysed the risk of postoperative outcomes at various time intervals between SARS-CoV-2 infection and the surgery date, providing updated evidence for guiding optimal surgery timing and minimising adverse postoperative outcomes.

METHODS

Study design and participants

In this retrospective cohort study, we initially recruited 7927 patients who were aged ≥18 years who underwent and required surgery at Guangdong Provincial People's Hospital in China between 1 December 2022 and 28 February 2023. Patients were excluded based on the following criteria: (1) those who underwent surgery with local anaesthesia alone (n=824); (2) those without reverse transcription-PCR or rapid antigen test results for COVID-19 (n=1151); (3) those with infection time beyond the observation period (n=729); (4) those who refused to participate (n=298) and (5) those lost to follow-up (n=1354). After applying these exclusion criteria, a final cohort of 3571 individuals remained for analysis (figure 1). Data on patient demographics, surgical procedures, SARS-CoV-2 infection status and postoperative complications within the first 30 days after surgery were collected from medical records and telephone follow-ups.

Assessment of SARS-CoV-2 infection

Confirmation of SARS-CoCoV-2 infection was established based on a positive outcome from either PCR testing or rapid antigen tests. The duration from surgery to the diagnosis of COVID-19 was defined as the period between the day of surgery and the date of the initial positive test result. In instances where patients underwent multiple surgeries, the surgical date closest to the time of infection was used for analysis. Consequently, patients were categorised into three groups as follows: those infected before

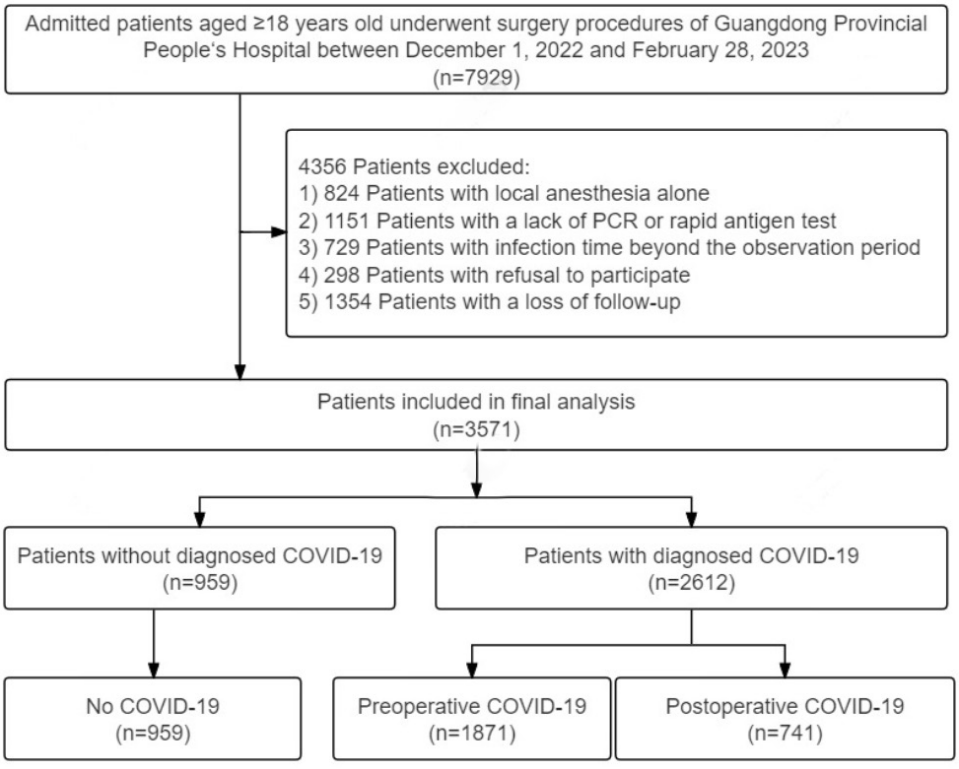

Figure 1 Flow chart of study design.

surgery (preoperative COVID-19), those infected within 30 days after surgery (postoperative COVID-19) and those with no positive SARS-CoV-2 test results during the study period (No COVID-19). The severity of COVID-19 was assessed and classified as either mild (WHO severity 1–3) or moderate/severe (WHO severity 4–9) based on the WHO Clinical Progression Scale (see the definition in online supplemental table 1).[28]

Definitions of postoperative complications

The outcome was defined as a composite of postoperative adverse events occurring within the initial 30 days following surgery (online supplemental table 2). This encompassed acute kidney injury (AKI), postoperative respiratory complications (including pneumonia, respiratory failure and pulmonary embolism), postoperative cardiovascular complications (including arrhythmia, myocardial infarction, acute heart failure, acute ischaemic heart disease, cardiac arrest, cardiogenic shock, cerebral haemorrhage, cerebral infarction, hypoxic-ischaemic encephalopathy, deep vein thrombosis, limb artery thrombosis, splenic infarction and hepatic infarction), unplanned secondary surgery, sepsis and mortality.

Covariates

The covariates encompassed age, sex, body mass index, smoking status, COVID-19 vaccination status, number of comorbidities (see the definition in online supplemental table 3), history of cancer, American Society of Anesthesiologists (ASA) grade classification (see the definition in online supplemental table 4), grade of surgery (see the definition in online supplemental table 5), urgency of surgery (see the definition in online supplemental table 6), duration of surgery, type of anaesthesia and type of surgery. We gathered such data from a variety of sources including electronic health records, laboratory data, anaesthesia information management systems and questionnaires. The proportions of missing data for key variables such as height, weight, smoking status and COVID-19 vaccination status were 2.30%, 0.25%, 11.12% and 5.58%, respectively. Median and mode imputation were employed to replace missing data for continuous and categorical variables, respectively.

Statistical analysis

Logistic regression was employed to estimate ORs with 95% CIs to examine the associations between the duration from surgery to COVID-19 diagnosis and the risk of postoperative complications, with No COVID-19 group as the reference category. We initially incorporated a restricted cubic spline term for the duration from surgery to the diagnosis of SARS-CoV-2 infection, using 3 knots at the 10th, 50th and 90th centiles into the model to explore the nonlinear relationship between the time frame and the risk of postoperative complications. We performed a subgroup analysis to explore whether trends in the risk of outcomes were consistent across surgical types. The assessment of nonlinearity was conducted using a likelihood ratio test to determine the associated p value. Following this, we categorised the time from COVID-19 diagnostic into discrete intervals, stratifying patients into four groups based on preoperative and postoperative COVID-19 statuses: within 1 week (pre-1w and post-1w), 1–2 weeks (pre-2w and post-2w), 2–3 weeks (pre-3w and post-3w) and beyond 3 weeks (pre-4w or more and post-4w or more).

The analysis was further divided to independently evaluate the associations between preoperative COVID-19 diagnostic time and postoperative complications, as well as those between postoperative COVID-19 diagnostic time and postoperative complications. Risks of postoperative complications were examined by stratifying the analysis based on age (younger elderly (<50 years) and older elderly (≥50 years)), smoking status (yes or no), COVID-19 vaccination status (yes or no), comorbidities (yes or no) and severity of COVID-19 (mild or moderate/severe).

We conducted sensitivity analysis to ensure the reliability of our results. We used a subset of the sample with complete data to replicate our main findings, examining any potential impact of missing values of sociodemographic factors. Furthermore, in light of the varying health statuses of patients undergoing emergency surgery and the surgeon's accurate judgement of the patient's condition, we conducted sensitivity analyses specifically focusing on patients undergoing elective surgery.

All analyses were performed using R V.4.3.0, with a two-tailed significance level of 0.05.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting or dissemination plans of this research.

RESULTS

Characteristics of patients

During the study period, 3571 patients were included in the study analysis (table 1). The median age of patients was 52 years (IQR 40–63 years), 45.42% were men and 92.92% were vaccinated against COVID-19. Of all individuals, 93.50% underwent elective surgery, 62.22% underwent major surgery and 85.69% had surgeries lasting no more than 4 hours. Patients were categorised into three groups based on the timing of COVID-19 diagnosis relative to surgery: No COVID-19 (n=959, 26.86%), preoperative COVID-19 (n=1871, 52.39%) and postoperative COVID-19 (n=741, 20.75%). Among patients with COVID-19, the majority experienced mild symptoms (94.22%), with only 5.45% and 6.61% exhibiting moderate or severe symptoms in preoperative and postoperative COVID-19, respectively. When compared with those with No COVID-19, patients with both preoperative and postoperative COVID-19 had lower rates of smoking, with 11.17% vs 14.29% for preoperative COVID-19 and 12.69% vs 14.29% for postoperative COVID-19, respectively. Patients with

Table 1 Characteristics of patients based on the time of diagnosis of COVID-19 relative to surgery

	Overall (n=3571)	No COVID-19 (n=959)	Preoperative COVID-19 (n=1871)	Postoperative COVID-19 (n=741)
Men, n (%)	1622 (45.42)	432 (45.05)	859 (45.91)	331 (44.67)
Age, years, IQR	52 (40, 63)	55 (44, 65)	50 (38, 61)	51 (39, 61)
BMI, kg/m^2, IQR	23.15 (20.93, 25.19)	23.05 (20.70, 24.97)	23.15 (20.95, 25.39)	23.21 (21.02, 25.15)
Smoking, n (%)	440 (12.32)	137 (14.29)	209 (11.17)	94 (12.69)
COVID-19 vaccination status, n (%)	3318 (92.92)	854 (89.05)	1755 (93.80)	709 (95.68)
Severity of COVID-19*, n (%)				
Mild	2461 (94.22)	NA	1769 (94.55)	692 (93.39)
Moderate/severe	151 (5.78)	NA	102 (5.45)	49 (6.61)
Number of comorbidities†, n (%)				
0	2323 (65.05)	564 (58.81)	1261 (67.40)	498 (67.21)
1	112 (3.14)	36 (3.75)	53 (2.83)	23 (3.10)
2	519 (14.53)	171 (17.83)	260 (13.90)	88 (11.88)
3	364 (10.19)	111 (11.57)	174 (9.30)	79 (10.66)
≥4	253 (7.08)	77 (8.03)	123 (6.57)	53 (7.15)
History of cancer, n (%)	1296 (36.29)	370 (38.58)	642 (34.31)	284 (38.33)
ASA classification, n (%)				
Grades 1–2	3048 (85.35)	792 (82.59)	1615 (86.32)	641 (86.50)
Grades 3–5	523 (14.65)	167 (17.41)	256 (13.68)	100 (13.50)
Grade of surgery, n (%)				
Minor	1349 (37.78)	337 (35.14)	743 (39.71)	269 (36.30)
Major	2222 (62.22)	622 (64.86)	1128 (60.29)	472 (63.70)
Urgent of surgery, n (%)				
Elective	3339 (93.50)	903 (94.16)	1741 (93.05)	695 (93.79)
Emergency	232 (6.50)	56 (5.84)	130 (6.95)	46 (6.21)
Duration of surgery, n (%)				
≤240 min	3060 (85.69)	811 (84.57)	1612 (86.16)	637 (85.96)
>240 min	511 (14.31)	148 (15.43)	259 (13.84)	104 (14.04)
General anaesthesia, n (%)	3402 (95.27)	929 (96.87)	1765 (94.33)	708 (95.55)
Type of surgery, n (%)				
Thoracic	821 (22.99)	179 (18.67)	454 (24.27)	188 (25.37)
Head and neck	518 (14.51)	154 (16.06)	263 (14.06)	101 (13.63)
Cardiovascular	336 (9.41)	103 (10.74)	154 (8.23)	79 (10.66)
Digestive	444 (12.43)	160 (16.68)	208 (11.12)	76 (10.26)
Breast	371 (10.39)	84 (8.76)	190 (10.15)	97 (13.09)
Gynaecologic and obstetrics	317 (8.88)	63 (6.57)	193 (10.32)	61 (8.23)
Orthopaedic	276 (7.73)	78 (8.13)	134 (7.16)	64 (8.64)
Other surgeries‡	488 (13.67)	138 (14.39)	275 (14.70)	75 (10.12)
Postoperative complications, n (%)	420 (11.76)	103 (10.74)	214 (11.44)	103 (13.90)

Continuous variables are described as median (IQR) and categorical variables are described as number (per cent).
*Due to 959 of the patients being No COVID-19, the total of severity of COVID-19 may not sum up to the overall study population size.
†Comorbidity included diabetes, chronic obstructive pulmonary disease, diffuse emphysema, bronchiectasis, asthma, pulmonary fibrosis, lung transplantation status, respiratory failure, hypertension, coronary artery disease, chronic heart failure, cardiomyopathy, ventricular aneurysm, pericardial disease, cerebrovascular disease, and chronic kidney disease.
‡Other surgeries included urological surgery, interventional surgery, plastic surgery, hernia surgery and neurosurgery.
ASA, American Society of Anesthesiologists; BMI, body mass index; NA, not available.

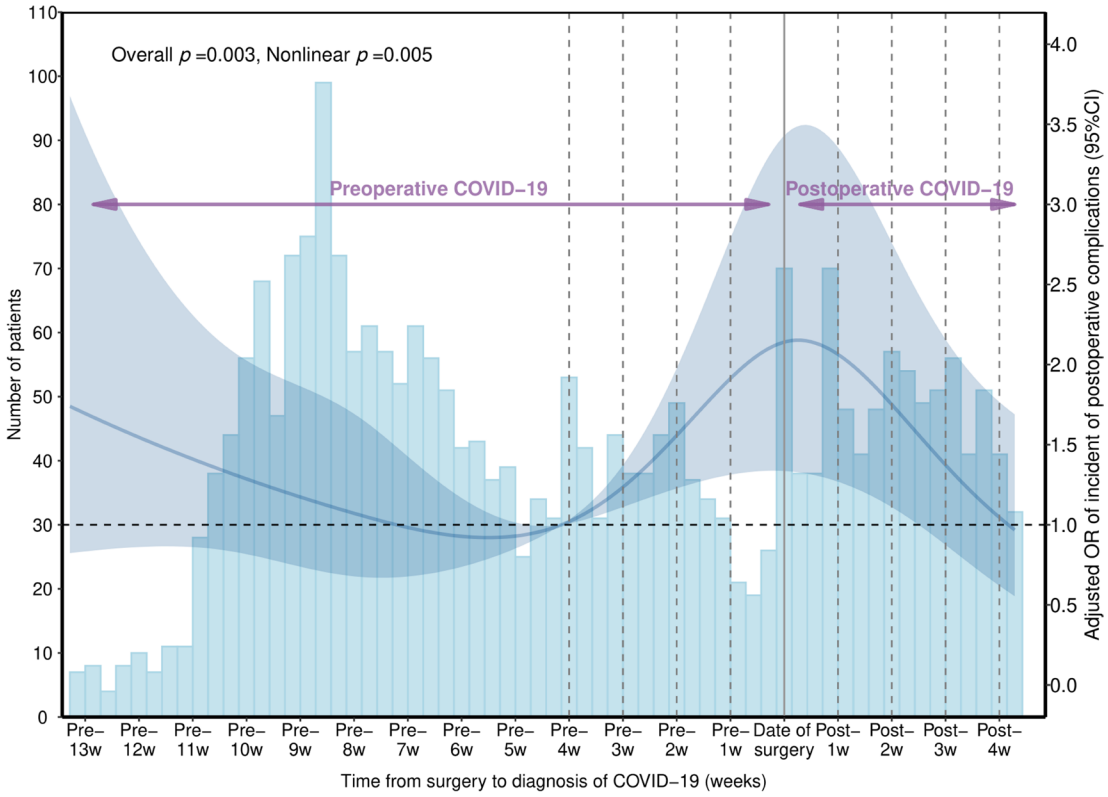

Figure 2 Relationship between time from surgery to diagnosis of COVID-19 and adjusted OR for incidence of postoperative complications. Included 2612 patients with perioperative COVID-19. On the x-axis, Pre means patients with preoperative COVID-19 and Post means patients with postoperative COVID-19.

No COVID-19 had a higher ASA classification than those with preoperative or postoperative COVID-19. The baseline characteristics of patients with and without postoperative complications are presented in online supplemental table 7.

Time-dependent association between duration from surgery to the diagnosis of COVID-19 and risk of postoperative complications

During the study period, 420 (11.76%) patients experienced postoperative complications. A higher rate (13.90%) of postoperative complications was observed in patients with postoperative COVID-19 compared with those with preoperative COVID-19 (11.44%). Among these postoperative complications, 217 (6.08%) cases were AKI, 135 (3.78%) were respiratory complications, 132 (3.70%) were cardiovascular complications, 51 (1.43%) were unplanned secondary surgeries, 23 (0.64%) resulted in mortality and 21 cases (0.59%) were sepsis (online supplemental figure 1).

We initially examined the non-linear trend in the association between the duration from surgery to the diagnosis of COVID-19 and the risk of postoperative complications (figure 2). Using the time interval between the surgery date and COVID-19 diagnosis as the axis of symmetry (dividing preoperative and postoperative by week), the risk curve exhibited a bell-shaped pattern, peaking approximately at the surgery date. The risk of postoperative complications was higher when SARS-CoV-2 infection occurred closer to the surgery date, regardless of whether it was preoperative or postoperative COVID-19. The risk diminished gradually as the time interval between the surgery date and COVID-19 diagnosis increased (p for nonlinearity=0.005). However, in cases of preoperative COVID-19, the risk did not decrease further beyond a 4-week interval, whereas in cases of postoperative COVID-19, it gradually diminished until 4 weeks after surgery. Further analysis across surgical categories revealed that cardiovascular procedures carried the highest perioperative infection risk, whereas no statistically significant difference was observed among head and neck, gynaecological and obstetric, and breast surgeries (online supplemental figure 2).

Association between preoperative COVID-19 and risk of postoperative complications

The risk of postoperative complications gradually decreased with an increase in the time interval between SARS-CoV-2 infection and surgery date (table 2). Compared with patients with No COVID-19, those with pre-1w exhibited the highest risk of postoperative complications (adjusted OR, aOR 2.67 (95% CI 1.50 to 4.78), p=0.001), followed by patients with pre-2w (aOR 2.14 (95% CI 1.20 to 3.80), p=0.010). Compared with patients with No COVID-19, there was no statistically significant increase in risk observed in patients with Pre-3w (aOR 1.27 (95% CI 0.67 to 2.39), p=0.46) or those with pre-4w or more (aOR 1.24 (95% CI 0.92 to 1.68), p=0.15).

Table 2 Association between preoperative and postoperative COVID-19 and risk of postoperative complications

		Postoperative complications					
		Model 1		Model 2		Model 3	
	Cases/total (%)	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Preoperative COVID-19 vs No COVID-19							
Time from surgery to diagnosis of COVID-19							
No COVID-19	103/959 (10.74)	Ref.		Ref.		Ref.	
Pre-1w	24/126 (19.05)	2.21 (1.34, 3.64)	0.002	2.42 (1.41, 4.15)	0.001	2.67 (1.50, 4.78)	0.001
Pre-2w	24/135 (17.78)	2.03 (1.23, 3.33)	0.005	2.26 (1.32, 3.87)	0.003	2.14 (1.20, 3.80)	0.010
Pre-3w	15/143 (10.49)	1.09 (0.61, 1.96)	0.76	1.14 (0.62, 2.09)	0.68	1.27 (0.67, 2.39)	0.46
Pre-4w or more	151/1467 (10.29)	1.06 (0.81, 1.38)	0.69	1.15 (0.86, 1.53)	0.34	1.24 (0.92, 1.68)	0.15
Postoperative COVID-19 vs No COVID-19							
Time from surgery to diagnosis of COVID-19							
No COVID-19	103/959 (10.74)	Ref.		Ref.		Ref.	
Post-1w	33/172 (19.19)	2.22 (1.43, 3.47)	<0.001	2.29 (1.41, 3.72)	0.001	2.48 (1.48, 4.13)	0.001
Post-2w	22/168 (13.10)	1.42 (0.86, 2.34)	0.17	1.61 (0.93, 2.78)	0.09	1.95 (1.10, 3.45)	0.023
Post-3w	22/180 (12.22)	1.44 (0.87, 2.39)	0.15	1.93 (1.12, 3.32)	0.018	2.25 (1.27, 3.98)	0.006
Post-4w or more	26/221 (11.76)	1.24 (0.77, 1.97)	0.38	1.34 (0.81, 2.23)	0.25	1.24 (0.72, 2.14)	0.44

Model 1: Adjusted for age (continuous) and sex (men or women).
Model 2: Additionally adjusted for BMI (continuous), smoking (yes or no), COVID-19 vaccination status (yes or no), number of comorbidities (0, 1, 2, 3, ≥4) and history of cancer (yes or no).
Model 3: Further adjusted for ASA classification (grades 1–2 or grades 3–5), grade of surgery (minor or major), urgency of surgery (elective or emergency), duration of surgery (≤240 min or >240 min), general anaesthesia (yes or no) and type of surgery (thoracic, head and neck, cardiovascular, digestive, breast, gynaecological and obstetrics, orthopaedic and other surgeries).
Pre-1w, preoperative COVID-19 within 1 week; Pre-2w, preoperative COVID-19 within 1–2 weeks; Pre-3w, preoperative COVID-19 within 2–3 weeks; Pre-4w or more, preoperative COVID-19 beyond 3 weeks.
Post-1w, postoperative COVID-19 within 1e week; Post-2w, postoperative COVID-19 within 1–2 weeks; Post-3w, postoperative COVID-19 within 2–3 weeks; Post-4w or more, postoperative COVID-19 beyond 3 weeks.
ASA, American Society of Anesthesiologists; BMI, body mass index.

Stratification analysis by the severity of COVID-19 revealed a higher risk of postoperative complications in patients with moderate or severe symptoms compared with those with mild symptoms (aOR 5.92 vs 2.04 with pre-1w, 5.12 vs 1.88 with pre-2w) (table 3). Stratification analysis by smoking status revealed an exceptionally high risk in smoking patients with pre-1w (aOR 17.22 (95% CI 3.87 to 76.70), p<0.001), while the aOR for non-smoking patients with pre-1w was 2.06 (95% CI 1.07 to 3.97, p=0.032). In summary, patients aged ≥50 years, smokers, those with comorbidities or those with moderate or severe symptoms were associated with a higher risk of postoperative complications in cases of preoperative COVID-19 within 2 weeks.

Association between postoperative COVID-19 and risk of postoperative complications

The risk of postoperative complications decreased roughly with the increase of the time interval between the surgery date and SARS-CoV-2 infection (figure 2). Compared with patients with No COVID-19, those with post-1w exhibited the highest risk of postoperative complications (aOR 2.48 (95% CI 1.48 to 4.13), p=0.001), followed by patients with post-3w (aOR 2.25 (95% CI 1.27 to 3.98), p=0.006) and those with post-2w (aOR 1.95 (95% CI 1.10 to 3.45), p=0.023) (table 2). Compared with patients with No COVID-19, the increased risk was not statistically significant in patients with post-4w or more (aOR 1.24 (95% CI 0.72 to 2.14), p=0.44).

Stratification analysis by the severity of COVID-19 revealed extremely high risks of postoperative complications in patients with post-1w with moderate or severe symptoms (aOR 11.52 (95% CI 4.36 to 30.45), p<0.001), as well as in patients with post-2w (aOR 14.96 (95% CI 3.69 to 60.60), p<0.001), and in patients with post-3w (aOR 29.42 (95% CI 4.47 to 193.81), p<0.001) (table 4). Conversely, no significant risk was observed among patients with mild symptoms. Stratification analysis by smoking status revealed consistently high risks in smoking patients, with aOR being 3.69 in post-1w, 5.05 inpost-2w, 6.33 in post-3w and 7.35 in post-4w or more, whereas the aOR for non-smoking patients with post-1w was 2.35 (95% CI 1.34 to 4.11), p=0.003). In summary, patients aged ≥50 years, smokers, those without COVID-19 vaccination, with comorbidities, or with moderate or severe symptoms were associated with a higher risk of postoperative complications in cases of postoperative COVID-19 occurring within 3 weeks.

Table 3 Stratification analysis of association between preoperative COVID-19 and risk of postoperative complications

Subgroup	No COVID-19	Pre-1w	Pre-2w	Pre-3w	Pre-4w or more
Age					
<50 (n=1247)	Ref.	1.78 (0.59, 5.32)	0.99 (0.31, 3.23)	0.90 (0.29, 2.73)	0.82 (0.46, 1.47)
≥50 (n=1583)	Ref.	3.34 (1.67, 6.70)	2.65 (1.36, 5.16)	1.46 (0.67, 3.18)	1.43 (1.00, 2.03)
Smoking					
No (n=2484)	Ref.	2.06 (1.07, 3.97)	2.31 (1.25, 4.25)	1.20 (0.60, 2.42)	1.12 (0.81, 1.55)
Yes (n=346)	Ref.	17.22 (3.87, 76.70)	1.65 (0.27, 10.03)	2.52 (0.51, 12.53)	2.54 (1.05, 6.15)
COVID-19 vaccination status					
No (n=221)	Ref.	2.97 (0.20, 44.55)	1.66 (0.08, 33.08)	1.94 (0.20, 18.96)	1.31 (0.51, 3.38)
Yes (n=2609)	Ref.	2.68 (1.47, 4.88)	2.14 (1.18, 3.89)	1.21 (0.62, 2.38)	1.24 (0.90, 1.71)
Comorbidity					
0 (n=1825)	Ref.	1.48 (0.46, 4.71)	2.60 (1.10, 6.12)	1.72 (0.60, 4.90)	1.47 (0.83, 2.59)
≥1 (n=1005)	Ref.	3.66 (1.80, 7.42)	2.03 (0.92, 4.47)	1.06 (0.48, 2.36)	1.17 (0.82, 1.66)
Severity of COVID-19					
Mild (n=2728)	Ref.	2.04 (1.02, 4.07)	1.88 (1.01, 3.50)	1.18 (0.59, 2.34)	1.29 (0.95, 1.77)
Moderate/severe (n=1061)	Ref.	5.92 (2.04, 17.18)	5.12 (1.11, 23.67)	2.40 (0.48, 12.09)	0.68 (0.29, 1.61)

Pre-1w, preoperative COVID-19 within 1 week; Pre-2w, preoperative COVID-19 within 1–2 weeks; Pre-3w, preoperative COVID-19 within 2–3 weeks; Pre-4w or more, preoperative COVID-19 beyond 3 weeks.
Values are odds ratios (ORs) with 95% confidence intervals (CIs), estimated from multivariable logistic regression models adjusted for age (continuous) and sex (men and women), BMI (continuous), smoking (yes or no), COVID-19 vaccination status (yes or no), comorbidities (yes or no), history of cancer (yes or no), ASA classification (grades 1–2 and grades 3–5), grade of surgery (minor or major), urgency of surgery (elective or emergency), duration of surgery (≤240 min or >240 min), general anaesthesia (yes or no) and type of surgery (thoracic, head and neck, cardiovascular, digestive, breast, gynaecologic and obstetrics, orthopaedic and other surgeries).
ASA, American Society of Anesthesiologists; BMI, body mass index.

Considering potential health status differences between patients who underwent emergency and elective surgery, a sensitivity analysis was conducted solely on patients who underwent elective surgery, and the findings remained consistent with the main results (online supplemental table 8). Additionally, to investigate the potential impact of missing values of sociodemographic factors, a sensitivity analysis was carried out on a subset of the sample without imputed data, revealing similar findings and trends to the main results (online supplemental table 9).

DISCUSSION

Our study underscored the importance of timing in the association between perioperative COVID-19 and the risk of postoperative complications. The risk significantly escalated when SARS-CoV-2 infection occurred closer to the surgery date, regardless of whether it is preoperative or postoperative. Besides, perioperative COVID-19 increased the risk of postoperative complications in specific subgroups, including older patients, smokers, those with comorbidities or those experiencing moderate or severe COVID-19 symptoms.

While there are existing recommendations regarding surgical decision-making following SARS-CoV-2 infection, a consensus has not yet been achieved in this regard. Study from the COVIDSurg and GlobalSurg Collaborative reported a significant increase in mortality when surgery was performed within 7 weeks after COVID-19 diagnosis during the prevaccine phase.[29] Additionally, the COVID-19 Research Database found that surgery performed 4–8 weeks after confirmed SARS-CoV-2 infection continues to carry an elevated risk of developing postoperative pneumonia.[30] However, emerging studies presented differing perspectives. A study conducted across 37 American centres revealed that the time span from a positive test to the actual surgery significantly impacted both mortality and pulmonary risk, with the risk subsiding after 2 weeks.[7] Conversely, research from 41 French centres found no significant association between surgery within 3 weeks of COVID-19 diagnosis and postoperative respiratory comorbidities.[27] Our research findings revealed a heightened risk of composite postoperative complications, encompassing respiratory, cardiovascular and other complications, when surgery was conducted within 2 weeks of a preoperative COVID-19 diagnosis. Therefore, conducting preoperative individualised risk assessments is imperative, and scheduling elective surgeries within 2 weeks after a SARS-CoV-2 diagnosis should be avoided. Our findings lend support to global endeavours aimed at updating restrictions on the timing of scheduled surgeries.

Furthermore, the risks of postoperative complications after SARS-CoV-2 infection varied across distinct subgroups. Our study revealed that older patients, smokers

Table 4 Stratification analysis of association between postoperative COVID-19 and risk of postoperative complications

Subgroup	No COVID-19	Post-1w	Post-2w	Post-3w	Post-4w or more
Age					
<50 (n=688)	Ref.	0.38 (0.10, 1.48)	1.58 (0.49, 5.10)	1.34 (0.43, 4.15)	0.41 (0.12, 1.42)
≥50 (n=1012)	Ref.	3.80 (2.13, 6.77)	2.01 (1.02, 3.95)	2.45 (1.25, 4.81)	1.74 (0.94, 3.23)
Smoking					
No (n=1469)	Ref.	2.35 (1.34, 4.11)	1.73 (0.92, 3.24)	1.82 (0.96, 3.47)	0.79 (0.41, 1.51)
Yes (n=231)	Ref.	3.69 (0.86, 15.81)	5.05 (0.99, 25.61)	6.33 (1.40, 28.59)	7.35 (1.84, 29.29)
COVID-19 vaccination status					
No (n=137)	Ref.	6.64 (0.78, 56.58)	2.64 (0.36, 19.27)	3.64 (0.29, 45.31)	0.54 (0.06, 4.74)
Yes (n=1563)	Ref.	2.19 (1.26, 3.80)	1.86 (1.01, 3.44)	2.27 (1.25, 4.14)	1.20 (0.68, 2.14)
Comorbidity					
0 (n=1062)	Ref.	2.73 (1.04, 7.18)	2.13 (0.72, 6.32)	2.48 (0.90, 6.78)	0.51 (0.10, 2.46)
≥1 (n=638)	Ref.	2.42 (1.32, 4.44)	2.13 (1.07, 4.23)	1.95 (0.95, 4.01)	1.64 (0.90, 2.98)
Severity of COVID-19					
Mild (n=1651)	Ref.	1.44 (0.77, 2.68)	1.26 (0.64, 2.45)	1.74 (0.94, 3.21)	1.11 (0.63, 1.98)
Moderate/severe (n=1008)	Ref.	11.52 (4.36, 30.45)	14.96 (3.69, 60.60)	29.42 (4.47, 193.81)	3.02 (0.60, 15.29)

Post-1w, postoperative COVID-19 within 1 week; Post-2w, postoperative COVID-19 within 1–2 weeks; Post-3w, postoperative COVID-19 within 2–3 weeks; Post-4w or more, postoperative COVID-19 beyond 3 weeks.
Values are odds ratios (ORs) with 95% confidence intervals (CIs), estimated from multivariable logistic regression models adjusted for age (continuous) and sex (men and women), BMI (continuous), smoking (yes or no), COVID-19 vaccination status (yes or no), comorbidities (yes or no), history of cancer (yes or no), ASA classification (grades 1–2 and grades 3–5), grade of surgery (minor or major), urgency of surgery (elective or emergency), duration of surgery (≤240 min or >240 min), general anaesthesia (yes or no) and type of surgery (thoracic, head and neck, cardiovascular, digestive, breast, gynaecologic and obstetrics, orthopaedic and other surgeries.
ASA, American Society of Anesthesiologists; BMI, body mass index.

and those with comorbidities faced an increased risk of adverse postoperative outcomes following SARS-CoV-2 infection. In a cohort of 3027 COVID-19-positive individuals, several risk factors were identified for mortality, including increased age, current smoking, presence of comorbidity and undergoing emergency surgery.[31] However, this study only considered patients with perioperative COVID-19 and did not compare them to those without infection. Moreover, our study also revealed that individuals with moderate or severe symptoms faced a markedly elevated risk of postoperative complications up to 2 weeks preceding their surgery, whereas those with mild symptoms exhibited a modest increase in complications. A study from the National COVID Cohort Collaborative (N3C) found that the impact of COVID-19 on postoperative outcomes is dependent on severity of illness, with only moderate and severe disease leading to higher risk of adverse outcomes.[32] Another study from N3C found that postoperative cardiovascular risk remained high even 8 weeks after infection with moderate or severe SARS-CoV-2 but did not increase among those undergoing surgery within 4 weeks following mild infection.[33] These studies failed to find an association between postoperative complications and mild COVID-19. Overall, it is essential for patients to undergo thorough evaluation before surgery, with a specific focus on assessing individual risk factors, to determine the optimal timing for surgical interventions.

There is limited research available on the risk of postoperative complications in patients who contract SARS-CoV-2 after surgery, with most prior studies focusing on series of total joint arthroplasty patients and overlooking the impact of other surgical procedures.[34 35] Another study of only 22 patients with COVID-19 occurring in the recovery period after open-heart surgery showed higher pneumonia and mortality rates in unvaccinated patients.[36] Our study revealed that individuals who tested positive for SARS-CoV-2 up to 3 weeks after surgery were at a higher risk of complications compared with those without the infection. Hence, robust postoperative management strategies to mitigate SARS-CoV-2 transmission risk are vital, with protective measures recommended for at least 3 weeks postsurgery. Our study highlighted the significance of monitoring a patient's SARS-CoV-2 infection status not only before but also after surgery.

The stratified analysis of patients with postoperative COVID-19 revealed that unvaccinated individuals, who were older, smokers or had comorbidities, faced a higher risk of complications. Furthermore, patients with moderate or severe symptoms of COVID-19 posed a significantly heightened risk of postoperative complications. Cardiovascular procedures demonstrated the

highest perioperative infection risk among surgical categories. Previous studies have shown that vaccination is effective in reducing the risk of severe illness, hospitalisation and death from COVID-19.[37 38] Recent work by the COVIDSurg Collaborative and GlobalSurg Collaborative reported that preoperative vaccination could prevent nearly 60 000 deaths per year on average among patients requiring elective surgery.[39] However, these studies did not account for postoperative SARS-CoV-2 infections. Our findings underscore the importance of reinforcing postoperative protective strategies for these vulnerable patients.

This study had several strengths. First, unlike previous research, our study not only focused on preoperative SARS-CoV-2 infections but also examined postoperative SARS-CoV-2 infections, providing recommendations for optimising surgical timing and improving postoperative management. Second, we investigated the interaction between various risk factors to gain further insight into the factors influencing postoperative complications. Third, we considered a broad range of surgical complications, including respiratory and cardiovascular morbidity, AKI, unplanned secondary surgery, sepsis and mortality, thereby enabling physicians to gain a comprehensive understanding of the overall perioperative risk. Fourth, patients were diagnosed with COVID-19 through PCR or antigen testing. Even uninfected patients were confirmed to have negative results, ensuring the reliability of the findings.

This study also had some limitations. First, the sample size was limited. Conducting further research with a larger sample size would provide a more comprehensive understanding of the interaction among various influencing factors. Second, the retrospective observational nature of the study made it challenging to completely rule out the influence of unmeasured residual confounding factors, despite efforts to retrieve as many covariates as possible. Third, the single-centre design of the study had limited the generalisability of the results and made it difficult to conduct a detailed subpopulation analysis. Fourth, patients with relevant symptoms were more likely to be tested for COVID-19. We excluded patients who did not undergo testing, which may explain the particularly high proportion of COVID-19 positive patients in the population. Despite the mentioned limitations, our study provided original and reliable evidence to support the relaxation of restrictions on the timing of scheduled surgery, as well as the importance of emphasising postoperative management to prevent postoperative infection.

In summary, our study has uncovered a critical time-dependent relationship between perioperative COVID-19 infection and the likelihood of postoperative complications, revealing an increased risk when the SARS-CoV-2 infection was closer to the date of surgery. Additionally, advanced age, the existence of comorbid conditions, absence of COVID-19 vaccination and symptom severity significantly influenced the risk of postoperative complications. Our findings not only contribute to the development of precise individual preoperative risk assessments but also offer evidence-based guidelines for postoperative care.

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Acknowledgements The authors would like to express their sincere gratitude to all the participants and staff of the study for their dedication and contribution to the research. We thank QiMin OuYang, YuQi Huang, Yuan Liang, XiaoMei Ling, JiaJun Shu, Shai Tang, MuYe Song, Kun Nie, JiaWen Li and other participants from Guangdong Provincial People's Hospital for the patients' follow-up. We also thank ShaoLi Zhou in The Third Affiliated of Sun Yat-sen University, HanBing Wang in The First People's Hospital of Foshan, and GaoFeng Zhao in Guangdong Provincial Hospital of Traditional Chinese Medicine for all their help in the conduct of this study. Thank Guangzhou AID Cloud Technology for the help of data collection, storage and management.

Contributors JM, HS, YL and JL conceived and designed the study. HS and JL administered the project and was responsible for data curation. JZ, FZ, LD and JL analysed and interpreted the data. JZ, FZ, LD, YZhang and XZhao wrote the first draft of manuscript. JZ, FZ, LD, YZhang, XZhao, HS and JL contributed to the interpretation of the results and revision of the manuscript. JZ, JM, YC, LC, JWang, YT, W-ZZ, GZ, LL, QZ, ZC, XX, LP, JWu, RL, DL, YZhu, XZhou, YW and RC got involved in data collection. All the authors approved the final version of the manuscript. HS is the guarantor; he had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analyses. All listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Funding Leading Talents in the Pearl River Talent Plan of Guangdong Province (KY012023288) and National Natural Science Foundation of China (U21A6002) to HS. National Natural Science Foundation of China (82073528, 81673156 and 81302417) to JL. National Key Clinical Specialty Construction Project (2021-2024, No. 2022YW030009) to JWu.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval The protocol of this study was approved by the Institutional Review Board of Guangdong Provincial People's Hospital (No. KY2023-031-02). Informed consent was obtained from all included patients in a text message or written way. The study adhered to the principles of the Declaration of Helsinki.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request.

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