Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Thoracic surgery outcomes for patients with Coronavirus Disease 2019

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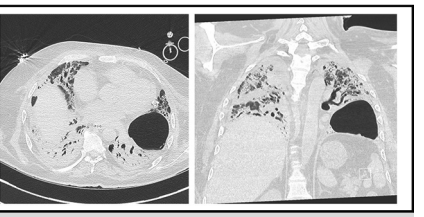
ABSTRACT

Objective: As the Coronavirus Disease 2019 pandemic continues, appropriate management of thoracic complications from Coronavirus Disease 2019 needs to be determined. Our objective is to evaluate which complications occurring in patients with Coronavirus Disease 2019 require thoracic surgery and to report the early outcomes.

Methods: This study is a single-institution retrospective case series at New York University Langone Health Manhattan campus evaluating patients with confirmed Coronavirus Disease 2019 infection who were hospitalized and required thoracic surgery from March 13 to July 18, 2020.

Results: From March 13 to August 8, 2020, 1954 patients were admitted to New York University Langone Health for Coronavirus Disease 2019. Of these patients, 13 (0.7%) required thoracic surgery. Two patients (15%) required surgery for complicated pneumothoraces, 5 patients (38%) underwent pneumatocele resection, 1 patient (8%) had an empyema requiring decortication, and 5 patients (38%) developed a hemothorax that required surgery. Three patients (23%) died after surgery, 9 patients (69%) were discharged, and 1 patient (8%) remains in the hospital. No healthcare providers were positive for Coronavirus Disease 2019 after the surgeries.

Conclusions: Given the 77% survival, with a majority of patients already discharged from the hospital, thoracic surgery is feasible for the small percent of patients hospitalized with Coronavirus Disease 2019 who underwent surgery for complex pneumothorax, pneumatocele, empyema, or hemothorax. Our experience also supports the safety of surgical intervention for healthcare providers who operate on patients with Coronavirus Disease 2019. (J Thorac Cardiovasc Surg 2021;162:1654-64)



Pneumatocele requiring resection in a patient with COVID-19.

CENTRAL MESSAGE

Patients with COVID-19 can develop complex unresolving pneumothoraces, pneumatoceles, empyemas, or hemothoraces that require thoracic intervention, which can be safely performed in selected patients.

PERSPECTIVE

We found that 0.7% of patients with COVID-19 admitted to the hospital developed complications requiring thoracic surgery. Of the 13 patients, a majority (77%) had a minimally invasive procedure, with 77% patient survival. Thoracic surgery is feasible in select patients with COVID-19. Earlier resection of pneumatoceles with air leak also may improve patient outcomes.

See Commentaries on pages 1665 and 1666.

The rapid spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and the resultant Coronavirus Disease 2019 (COVID-19) pandemic have brought incredible challenges in understanding how to best care for critically ill patients. Although other respiratory viruses can also progress to acute respiratory distress syndrome (ARDS), early research shows that SARS-CoV-2 results in a number of unique systemic and end-organ derangements,[1-3] with a different phenotype than standard ARDS.[4] The consequences of this pathophysiology may lead to the increased pulmonary and thoracic complications requiring surgical intervention.

ARDS caused by COVID-19 often leads to a reduction in lung compliance.[4] Because of the high peak end-expiratory pressure required to ventilate patients, as well as distinct

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Scanning this QR code will take you to the table of contents to access supplementary information.

Abbreviations and Acronyms

ARDS = acute respiratory distress syndrome
COVID-19 = Coronavirus Disease 2019
CT = computed tomography
PPE = personal protective equipment
rtPCR = reverse transcriptase polymerase chain reaction
SARS-CoV-2 = severe acute respiratory syndrome coronavirus 2
VATS = video-assisted thoracoscopic surgery
VV-ECMO = veno-venous extracorporeal membrane oxygenation

pulmonary pathology,[5] patients with COVID-19 have a higher incidence of barotrauma compared with patients with ARDS due to other causes.[6] Other patients with COVID-19 develop pneumatoceles,[7] which are thin-walled, air-filled cysts in the lung parenchyma that are sequelae of pneumonia.[8]

Hypercoagulability is common in patients with COVID-19, with many patients expressing elevated D-dimer levels and sustaining a high incidence of arterial thrombosis, pulmonary embolism, and often mortality due to thromboembolic complications.[1] Although guidelines regarding anticoagulation vary, the high rate of thrombosis has led to some critically ill patients with COVID-19 being placed on therapeutic anticoagulation.[9] Additionally, some patients with COVID-19 may require further respiratory support, such as veno-venous extracorporeal membrane oxygenation (VV-ECMO),[10] which is another indication for anticoagulation.

The potential consequences of barotrauma, pneumatoceles, and therapeutic anticoagulation are pulmonary or pleural complications that may require surgical intervention. Little data are reported regarding the need for and efficacy of thoracic surgery for sequelae of COVID-19. The primary purpose of this study is to evaluate what complications develop in patients with COVID-19 that require thoracic surgery at a tertiary hospital in New York City. We also will describe the operations performed and early outcomes for these patients, and evaluate the safety of performing thoracic surgery operations for healthcare providers.

MATERIALS AND METHODS

Study Design

This study is a single-institution retrospective case series evaluating all patients who were positive for COVID-19, who were admitted to the hospital at New York University Langone Health Manhattan campus, and who underwent thoracic surgery between March 13, 2020 (the time of first admission), and August 8, 2020. Data collection was performed on September 8, 2020, to allow for 30-day follow-up. Patients were deemed positive for COVID-19 by reverse transcriptase polymerase chain reaction (rtPCR). Thoracic surgery was defined as any procedure performed in the operating room that involved the thoracic cavity, including pleural procedures and pulmonary resection. All patients with COVID-19 requiring thoracic surgery were included. There were no exclusion criteria, although each patient was assessed by a thoracic surgeon who determined the need for surgical intervention. The New York University Langone Health Institutional Review Board approved this human subject study (Institutional Review Board S20-00485), and data were collected from direct chart review.

Indications for Surgery

All patients with clinically significant pneumothoraces underwent tube thoracostomy. Patients with a chest tube and nonresolving air leaks after 2 weeks who could not tolerate water seal underwent a chest computed tomography (CT) to further evaluate their pleural space and lung parenchyma, and ability to undergo thoracic surgery. Additionally, patients with chest tubes and continued large pneumothorax were evaluated for surgical management.

Patients who were febrile with a loculated empyema were evaluated for empyema evacuation and decortication. All patients with a loculated hemothorax that was still present after tube thoracostomy were evaluated for possible hemothorax evacuation and decortication. Furthermore, all patients with worsening respiratory status or hypotension secondary to active bleeding or expanding pneumothorax despite chest tube placement were also taken to the operating room for management.

Perioperative Care

All operations were performed in negative pressure operating rooms. Personal protective equipment (PPE) in the operating room consisted of a hair cover, N95 mask, eye protection, nonsterile gown, and gloves throughout the entirety of the procedure. During intubation, nonanesthesia personnel were asked to wait outside the operating room. Once the patient was intubated, bronchoscopy was performed, by the anesthesiologist or the surgical service if needed, to position the double lumen tube. For hemodynamically unstable patients, the existing tracheostomy or single lumen tube was used for intraoperative ventilation. Standard intraoperative sterile PPE with an N95 mask was used for the operation (Video 1). Thoracic surgery was performed by 1 of 4 thoracic surgeons, with the assistance of a cardiothoracic surgery resident. Patients were readmitted to a dedicated COVID-19 intensive care unit postoperatively.

Outcomes

The primary outcome for this study is to report the incidence and describe the complications of COVID-19 that required thoracic surgery. The secondary outcomes for this study are the early outcomes from the operations and healthcare provider safety, defined as freedom from conversion from a negative to positive COVID-19 rtPCR test result. All healthcare providers were screened for COVID-19 symptoms (fever, cough, shortness of breath, chills, myalgia, diarrhea, and headaches), and all underwent rtPCR testing on a monthly basis.

RESULTS

Patients Who Underwent Thoracic Surgery

From March 13, 2020, to July 18, 2020, 1899 patients with a positive rtPCR test result for COVID-19 were admitted to Manhattan Tisch Hospital. During this time period, 13 patients (0.7%) who were hospitalized for COVID-19 underwent thoracic surgery. All 13 patients (100%) were male. Patient characteristics are summarized in Table 1.

Surgical Procedures

Among 13 patients, 17 operations were performed. Two patients (15%) had multiple operations due to ongoing

VIDEO 1. Demonstration of intraoperative PPE use. Operating room staff wearing PPE during thoracic surgery in a patient with COVID-19. All nonsterile personnel are wearing a gown, gloves, eye protection, N95, and hair cover. All sterile personnel are wearing the standard sterile gown, sterile gloves, eye protection, and hair cover, with the use of an N95 mask versus a standard operating room mask. Video available at: https://www.jtcvs.org/article/S0022-5223(21)00168-9/fulltext.

TABLE 1. Patient demographics

Variable	Patients with COVID-19 requiring thoracic surgery (n = 13)
Gender, no. (%)	
Male	13 (100)
Female	0 (0)
Age, median (IQR), y	46 (38-60)
BMI, median (IQR), kg/m^2	27 (25-29)
Comorbidities, no. (%)	
Active malignancy	0 (0)
Asthma/COPD	0 (0)
Coronary artery disease	0 (0)
Diabetes	2 (15)
End-stage renal disease on dialysis	1 (8)
Hypertension	2 (15)
Known pulmonary embolism or deep venous thrombosis	1 (8)
Right ventricular failure/pulmonary hypertension	1 (8)
Stroke	2 (15)
Total with any comorbidity, no. (%)	4 (31)
Complication requiring surgery, no. (%)	
Unresolving complex pneumothorax	2 (15)
Pneumatocele with ongoing air leak	5 (38)
Empyema	1 (8)
Hemothorax	5 (38)

COVID-19, Coronavirus Disease 2019; *IQR*, interquartile range; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disease.

bleeding. Of the 17 operations, 10 (61%) were performed in a minimally invasive fashion, which accounts for the operations in 10 (77%) of the 13 patients. Of the 3 patients who required thoracotomy, 2 underwent operation for ongoing hemorrhage with hemodynamic instability and 1 had acute respiratory distress during induction (Table 2).

Two patients (15%) required surgery for complicated nonresolving pneumothoraces with ongoing air leak. Both patients had multiple chest tube placements with continued pneumothoraces, which were evaluated with chest CT (Figure 1). One patient underwent a robotic lysis of adhesions and decortication, with a small wedge resection of necrotic lung. The second patient underwent a video-assisted thoracoscopic surgery (VATS) lysis of adhesions with chest tube placements.

Five patients (38%) underwent surgery for continued air leak, with 1 or more pneumatoceles on chest CT (Figure 2). Of these 5 surgeries, 1 procedure (20%) was performed robotically, 3 procedures (60%) were performed via VATS, and 1 procedure (20%) was a thoracotomy. One patient had an unresolving recurrent pneumothorax who underwent a robotic left lower lobe pneumatocele unroofing and decortication. The 3 VATS resections were also for unresolving recurrent pneumothoraces with active air leaks and the presence of pneumatoceles on chest CT, with 1 patient undergoing a right VATS resection of blebs in all 3 lobes, 1 patient undergoing a right VATS upper lobe pneumotocele unroofing and decortication, and 2 patients undergoing a left VATS pneumatocele resection and decortication. The thoracotomy was performed for a patient with a large loculated right pneumothorax with bilateral pneumatoceles and worsening hypoxia, hypercarbia, and hypotension despite right chest tubes who underwent decortication, unroofing of the pneumatocele, and pericardial window. Of note, 3 (60%) of the 5 patients were former smokers.

TABLE 2. Patient-specific details regarding demographics, laboratory results, indications for surgery, surgical procedure, and outcomes

Patient	Age, y	Gender	Race	BMI	Comorbidities	Admit date	COVID-19 treatments	Respiratory status at surgery	Date of surgery	Surgery	Indication
1	60	M	White	34	None	3/30/2020	Tocilizumab, sarilumab	On nasal cannula, O2 sat 62% upon entering the OR	5/12/2020 (HD 42)	Left robotic decortication, lower lobe wedge resection	Multicystic lung disease, large pneumothorax with worsening respiratory status despite chest tube, prior large effusion
2	52	M	Asian	25	None	5/2/2020	Convalescent plasma, tocilizumab	Intubated	5/21/2020 (HD 19)	Right robotic decortication, lower lobe wedge resection	Large loculated hydropneumothorax, empyema
3	72	M	White	27	Diabetes, hypertension, acute renal failure, stroke	3/15/2020	Azithromycin/ plaquenil, lopinavir/ ritonavir, steroids	Trached	6/3/2020 (HD 78)	Right VATS hemothorax evacuation, decortication, lower lobe wedge resection	Admission complicated by pseudomonas pneumonia, stroke, acute renal failure, encephalopathy, hypoxic arrest with post-CPR pneumothorax. He developed an iatrogenic hemothorax (10 × 12 cm) and was taken to the OR.
4	35	M	White	31	Pulmonary hypertension, right ventricle failure	4/4/2020	Tocilizumab, steroids	Trached, in extremis	6/1/2020 (HD 57)	Left chest tube for new left pneumothorax, right VATS converted to thoracotomy due to hemodynamic instability, decortication, right upper lobe pneumatocele resection, pericardial window	Recurrent right pneumothorax s/p 3 chest tubes, right upper lobe endobronchial valve placement, with acute decompensation on HD 57 with pCO2 170, tachycardia, hypoxia, hypotension, and large pneumothorax with transient improvement after needle decompression, but still with O2 sat 50%-70%
5	66	M	Asian	29	Hypertension, hyperlipidemia	3/26/2020	Azithromycin/ plaquenil, hydroxychloroquine, tocilizumab	room air	5/14/2020 (HD 58)	Left VATS hemothorax evacuation, decortication of left lower lobe	Chest x-ray done at rehabilitation showed left sided atelectasis, then CT with large hemothorax. Hemothorax incompletely drained with pigtail catheter, taken to OR for washout.
6	65	M	White	25	None	3/26/2020	Azithromycin/ plaquenil, tocilizumab	Intubated	5/8/2020 (HD 42)	Right VATS bleb resections from right upper, middle, and lower lobes	Hypoxia with inability to ventilate due to massive alveolar pleural leak
7	60	M	Asian	26	None	4/10/2020	Azithromycin/ plaquenil	On nasal cannula O2 sat 62% upon entering the OR	5/18/2020 (HD 37)	Left robotic decortication of empyema, resection of pneumatocele, wedge resection of consolidated/ diseased lung, decortication	Pneumothoraces unresolved by prolonged chest tube placement.
8	33	M	Hispanic	30	None	3/26/2020	Azithromycin/ plaquenil, nitrazoxanide	Trached, on VV-ECMO	4/29/2020 (HD 33)	Right anterolateral thoracotomy, hemothorax evacuation, RLL wedge resection × 2 for ruptured hematoma, chest packed	Chest tube placement on anticoagulation for spontaneous pneumothorax, followed by hemothorax with hemodynamic instability

(Continued)

TABLE 2. Continued

Patient	Age, y	Gender	Race	BMI	Comorbidities	Admit date	COVID-19 treatments	Respiratory status at surgery	Date of surgery	Surgery	Indication
9	31	M	White	25	Diabetes	3/25/2020	Azithromycin/ plaquenil, nitazoxanide, tocilizumab	Trached, on VV-ECMO	5/7/2020 (HD 42)	Right VATS with 5-cm anterolateral thoracotomy, evacuation of loculated right effusion, partial decortication	Persistent loculated pleural effusion
10	40	M	Hispanic	29	Obesity, hyperlipidemia	4/5/2020	Azithromycin/ plaquenil, tocilizumab, remdesivir, steroids	Trached, weaned off VV-ECMO	5/14/2020 (HD 38)	Right VATS hemothorax evacuation, decortication of RUL, RML, RLL	Incompletely drained right hemothorax causing inadequate lung expansion
11	46	M	Hispanic	25	Prior smoker	4/2/2020	Azithromycin/ plaquenil, clazakizumab RTC, steroids	Trached, on VV-ECMO	7/3/2020 (HD 92)	Right VATS hemothorax evacuation, decortication, right upper lobe blebectomy	Bilateral blebs with pneumothoraces requiring chest tubes, development of right hemothorax
12	43	M	Hispanic	27	Active smoker	4/17/2020	Plaquenil, tocilizumab, remdesivir, steroids	Trached, on VV-ECMO	7/7/2020 (HD 81)	Left VATS converted to axillary thoracotomy, decortication, LUL and LLL bleb resection	Unable to wean VV-ECMO support, large left pneumatocele/bleb
13	38	M	White	24	None	3/30/2020	Azithromycin/ plaquenil, possibly IL6RI/ sarilumab RCT, stem cell infusion, IVIG, anakinra, steroids	Trached, weaned off VV-ECMO	6/23/2020 (HD 86)	Right VATS partial lysis of adhesions and placement of 2 chest tubes, trach exchange	Persistent pneumomediastinum after chest tube placement

Patient	WBC: Admission	WBC: Preoperative	WBC: Postoperative	D-dimer: Admission	D-dimer: Preoperative	D-dimer: Postoperative	Necrotic lung	Pathology	Postoperative course	Outcome
1	6.8	33	34.5	244	1256	831	Yes	Extensive pulmonary arterial organizing thrombi, pulmonary infarcts with necrosis and abscess formation and reactive squamous metaplasia. Scattered fibrin thrombi in parenchymal arterioles/venules	Postoperative air leak, resolved within 1 wk	Discharged
2	13.1	27.6	29.1	187	2503	1122	Yes	Pulmonary infarct and abscess. Multiple organizing pulmonary arterial thromboemboli. Residual hyaline membranes in the infarct areas.	Cultures grew *Klebsiella* pneumonia	Discharged
3	14.6	25.1	22.6	869 (HD 7)	1033 (6/1)	1009	Yes	Parenchymal abscess with hematoma. Patchy end-stage fibrosis with metaplasia.	Progressive pressor requirement and transition to comfort care on POD 2	Dead

(Continued)

TABLE 2. Continued

Patient	WBC: Admission	WBC: Preoperative	WBC: Postoperative	D-dimer: Admission	D-dimer: Preoperative	D-dimer: Postoperative	Necrotic lung	Pathology	Postoperative course	Outcome
4	9.6	9.2	Died	230	903	Died	No	None	Continued postoperative hypercarbia and hypotension, with comfort care on POD 1	Dead
5	9.8	8.6 (5/12)	14.1	7824	1049 (5/12)	Not checked	No	None	Admitted back to rehabilitation on POD 7	Discharged
6	7.9	15.6	16.3	2226	437	549	Yes (cystic lung destruction)	Organizing pneumonia. Organizing phase of diffuse alveolar damage. Fibrous pleuritis.	Ongoing leaks from alveolar pleural fistulas, inability to keep negative suction on chest tubes, multisystem organ failure, distributive shock, made hospice	Dead
7	9.4	6.1	10.3	693	Not checked	Not checked	No	Organizing pneumonia with chronic inflammation	Discharged with chest tubes, removed, then reaccumulation of pneumothorax. Discharged again with thopaz, later removed.	Discharged
8	9.6	7.9	18.7	645	6769	>10,000	Yes	Hemorrhagic infarction with cavities resulting from ischemic necrosis of the lung parenchyma and alveolar hemorrhage	Taken back to OR on POD1 for ongoing hemorrhage, underwent RLL lobectomy	Discharged
9	8.8	6.9	9.9	223	1680	2186	No	None	Taken back to OR on POD 1 and POD 2 for retained hemothorax requiring chest packing	Discharged
10	10.6	7.5	12.9	450	1780	1427		None	Chest tubes removed by POD 14	Discharged
11	7.9	8.4	9.1	560	2041	663		Pulmonary bleb, thrombus, chronic pleuritis with granulation tissue	Later developed a large complex left multiloculated pneumothorax, multiple pneumatoceles, and alveolar pleural fistula requiring left VATS adhesiolysis. Decannulated from VV-ECMO.	Discharged

(Continued)

TABLE 2. Continued

Patient	WBC: Admission	WBC: Preoperative	WBC: Postoperative	D-dimer: Admission	D-dimer: Preoperative	D-dimer: Postoperative	Necrotic lung	Pathology	Postoperative course	Outcome
12	10.4	13.5	31.1	249	720	934	No	Organizing diffuse alveolar damage with residual hyaline membranes, pleuritis, and pneumatocele lined by inflammation including giant cells	Decannulated from VV-ECMO, left chest tube remains, continues to require ventilation support	Alive, inpatient
13	8.4	16	15.8	508	938	852	No	None	Resolved pneumothorax with removal of chest tube and discharge to rehabilitation.	Discharged

BMI, Body mass index; *COVID-19*, Coronavirus Disease 2019; *HD*, hospital day; *VATS*, video-assisted thoracoscopic surgery; *CPR*, cardiopulmonary resuscitation; *IVIG*, intravenous immunoglobulin; *OR*, operating room; *VV-ECMO*, veno-venous extracorporeal membrane oxygenation; *RUL*, right upper lobe; *RML*, right middle lobe; *RLL*, right lower lobe; *LUL*, left upper lobe; *LLL*, left lower lobe; *RCT*, randomized control trial; *WBC*, white blood cell count; *POD*, postoperative day.

One patient (8%) had a multi-loculated right hydropneumothorax (Figure 3), concerning for empyema due to a white blood cell count of 25,000 cells/μL, fever, and hypotension consistent with sepsis. A robotic right decortication was performed. The patient was also noted to have a partially necrotic right lower lobe adjacent to the inferior pulmonary ligament, with resection of the necrotic area. Operative cultures grew *Klebsiella* pneumonia.

Five patients (38%) developed a hemothorax that required surgery (Figure 4). Three patients (60%) underwent VATS hemothorax evacuation, and 2 patients (40%) had a thoracotomy secondary to ongoing hemorrhage. The VATS procedures were all hemothorax evacuations and decortications, with 1 of the patients having an area of necrosis in the right lower lobe that was removed by a wedge resection. One thoracotomy was a hemothorax evacuation for active hemorrhage from the chest wall and diaphragm. The other was a hemothorax evacuation and right lower lobectomy for an infarcted right lower lobe secondary to venous thrombosis.[11] All 5 patients were on therapeutic anticoagulation before development of the hemothorax. Indications for therapeutic anticoagulation were presumed pulmonary embolus in 1 patient, lacunar infarcts in 1 patient, elevated D-dimer greater than 10,000k in 1 patient, and VV-ECMO in 2 patients. All patients on VV-ECMO were anticoagulated using a heparin infusion, with a goal anti-factor Xa greater than 0.15 IU/mL and a partial thromboplastin time less than 70 seconds.[12] Although 2 hemothoraces were spontaneous, 3 were postprocedural after tube thoracostomy in 2 patients or after central line placement in 1 patient.

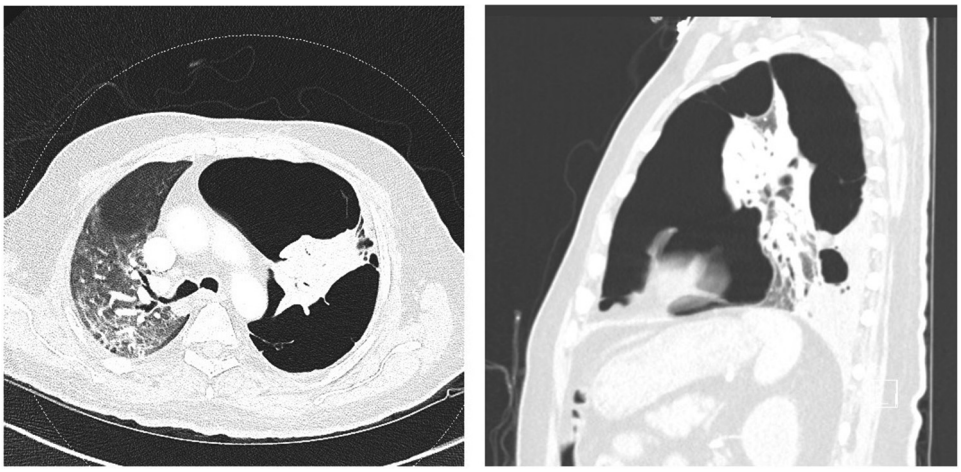

FIGURE 1. Chest CT of complex pneumothorax. Chest CT scan of a patient with COVID-19 with axial (left) and sagittal (right) views of a nonresolving complex pneumothorax despite tube thoracostomy (not pictured in these images). This patient required surgical intervention.

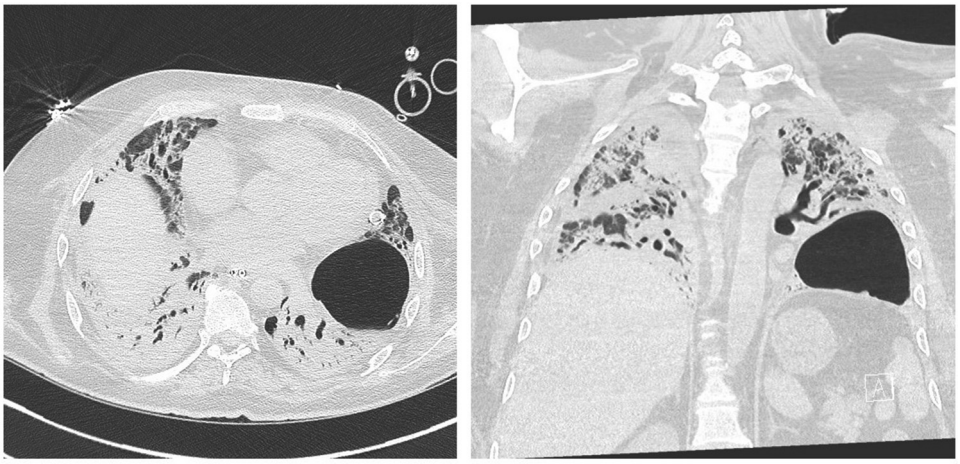

FIGURE 2. Chest CT of pneumatocele. Chest CT scan of a patient with COVID-19 with axial (left) and coronal (right) views of a pneumatocele in a patient with a persistent active air leak. This patient required a surgical intervention for pneumatocele resection.

Evaluation of Patient Outcomes

Among the 13 patients who underwent thoracic surgery, 9 (69%) have been discharged from the hospital and are on room air, 3 (23%) have died postoperatively, and 1 (8%) remains hospitalized (Figure 5). Patient characteristics and outcomes for each COVID-19 complication requiring surgery are shown in Table 3.

The postoperative mortalities were due to respiratory failure in 2 patients and multisystem organ failure in 1 patient. Both patients with pneumatoceles who died postoperatively had ongoing active air leaks after resection, with worsening hypoxic and hypercarbic respiratory failure. The patient who died after a hemothorax evacuation had acute renal failure before surgery, with worsening renal failure and new-onset liver failure leading to death postoperatively.

Healthcare Provider Safety

Four thoracic surgeons, 3 residents, and 2 thoracic anesthesiologists performed all thoracic surgeries in patients with COVID-19 during this time frame. One resident tested positive for COVID-19 before the first thoracic surgical case on a patient with COVID-19. The remaining 8 healthcare providers have tested negative by COVID-19 rtPCR testing on a monthly basis, and all remain antibody negative. All healthcare providers were screened daily for symptoms, which would have required quarantine, although none developed any symptoms. No operating

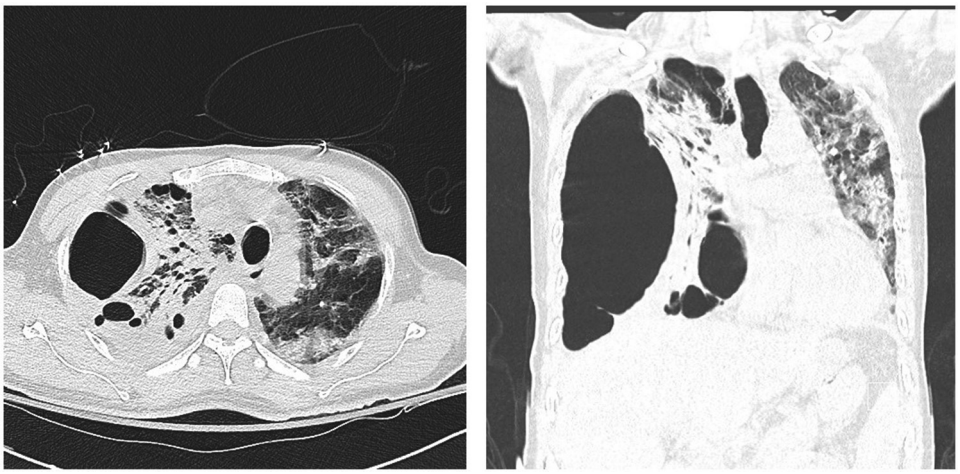

FIGURE 3. Chest CT of loculated hydropneumothorax/empyema. Chest CT scan of a patient with COVID-19 with axial (left) and coronal (right) views of the patient with a loculated hydro-pneumothorax, with a basilar chest tube (not pictured in these CT slices) in place. This patient had a leukocytosis with concern for empyema, underwent a decortication, and grew *Klebsiella pneumonia* from the fluid collection.

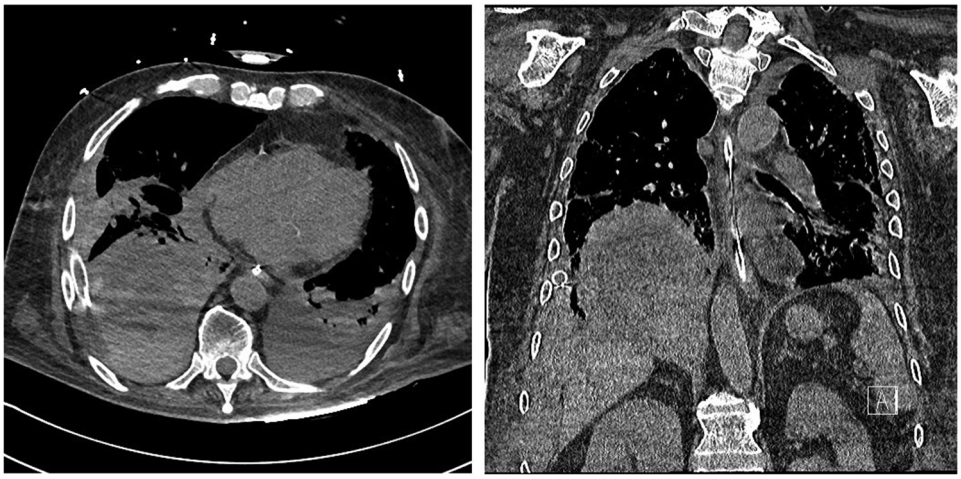

FIGURE 4. Chest CT of hemothorax. Chest CT scan of a patient with COVID-19 with axial (left) and coronal (right) views of a right hemothorax that occurred after a right chest tube placement in a patient on therapeutic anticoagulation. Because of retained hemothorax, this patient was taken to the operating room for a hemothorax evacuation.

room staff contracted COVID-19 after a workplace exposure.

DISCUSSION

This series demonstrates that only 0.7% of patients admitted with COVID-19 required thoracic surgery. Reasons for operative intervention included unresolving pneumothorax, pneumatocele with continued air leak, empyema, and hemothorax. These patients were critically ill with prolonged COVID-19 courses, with the median date of surgery on hospital day 43 (interquartile range, 42-78). Despite a high mortality of intensive care unit patients with COVID-19,[13,14] a majority (69%) of the patients who were operated on have been discharged, with a current survival of 77%. Patients who died were high risk, with progressive respiratory distress leading to acute surgical

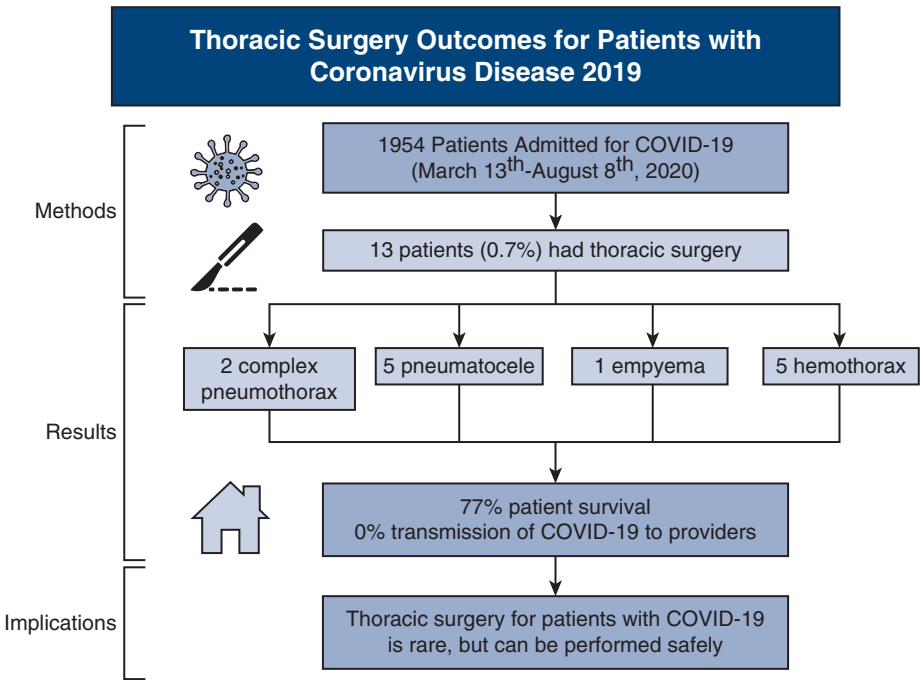

FIGURE 5. Flowchart demonstrating the main findings of this study. Of the 1954 patients admitted during the study period for COVID-19, 13 (0.7%) required thoracic surgery for the following indications: 2 pneumothoraces, 5 pneumatoceles, 1 empyema, and 5 hemothoraces; 77% of the patients survived, with no transmission of COVID-19 to any providers. Although rare, thoracic surgery for complications associated with COVID-19 is feasible and safe for patients and providers. *COVID-19,* Coronavirus Disease 2019.

TABLE 3. Characteristics and outcomes of thoracic surgery for patients with Coronavirus Disease 2019

Variable	Pneumothorax (n = 2)	Pneumatocele (n = 5)	Empyema (n = 1)	Hemothorax (n = 5)	All patients (n = 13)
Hospital day of surgery, median (IQR)	63.5 (42-85)	57 (42-81)	19	43 (42-48)	43 (42-78)
Postoperative length of stay, d, median (IQR)	33 (14-52)	5 (4-6) (n = 3)	21	22 (8-34)	14 (5.5-28)
Smoking history, no. (%)	0 (0)	3 (60)	0 (0)	1 (20)	4 (31)
Anticoagulation, no. (%)	1 (50)	1 (20)	1 (100)	5 (100)	8 (62)
Type of resection, no. (%)					
Robotic	1 (50)	1 (20)	1 (100)	0 (0)	3 (23)
VATS	1 (50)	3 (60)	0 (0)	3 (60)	7 (54)
Thoracotomy	0 (0)	1 (60)	0 (0)	2 (40)	3 (23)
Necrotic lung present, no. (%)	1 (50)	0 (0)	1 (100)	2 (40)	4 (31)
Patient outcomes					
Alive, discharged home	2 (100)	1 (40)	1 (100)	4 (80)	9 (69)
Alive, remains inpatient	0 (0)	1 (20)	0 (0)	0 (0)	1 (8)
Mortality	0 (0)	2 (40)	0 (0)	1 (20)	3 (23)

IQR, Interquartile range; *VATS,* video-assisted thoracoscopic surgery.

intervention or age more than 70 years with multiple comorbidities. Therefore, standard high-risk patients for thoracic procedures that may normally lead to a prolonged hospital course or other morbidity are more likely to result in death if they have concurrent COVID-19.

Although individual case reports of pneumatoceles in COVID-19 have been described,[15] this is the largest cohort with 5 patients requiring surgery. Most pneumatoceles are described in children and frequently spontaneously resolve. For the patients described in this article, all 5 required surgery for continued air leaks, with 4 patients in worsening respiratory failure from difficulty ventilating. Because of the existing poor ventilation, with fragile pulmonary parenchyma associated with pneumatoceles, 2 of the patients (40%) had progressive postoperative respiratory failure leading to death. Despite this high mortality rate, both of those patients were in progressive respiratory distress that would have resulted in death without surgical intervention. The other 2 patients with pneumatoceles and difficult ventilation were on ECMO and have now been weaned off ECMO support. Notably, the patient with a pneumatocele with an air leak but no respiratory distress was discharged on postoperative day 5 and remains home on room air. Perhaps, for patients with COVID-19 complicated by pneumatoceles and an associated pneumothorax, more prompt surgical intervention, before worsening respiratory condition, is warranted.

Hemothoraces requiring surgical intervention occurred in 5 patients, all of whom were receiving therapeutic anticoagulation. Although the rate of hemothorax requiring surgery is unknown (the number of hospitalized patients on therapeutic anticoagulation during this time is unavailable), postprocedural hemothorax occurred in 3 patients and spontaneous hemothorax occurred in 2 patients. This bleeding risk requiring intervention should be taken into consideration when weighing the risks and benefits of therapeutic anticoagulation.

Regarding efficacy of surgery for bleeding, the only patient in this group who died postoperatively was aged more than 70 years, with acute renal failure, a stroke, and cardiac arrest previously during his hospital stay. Because of the patient's large hemothorax with inability to wean from the ventilator, surgery was performed. However, given his age and comorbidities, the postoperative liver failure and resultant mortality are likely due to patient-specific factors. The remaining 4 patients (80%) have all been discharged, indicating that surgery for bleeding in patients with COVID-19 is reasonable.

A secondary finding in this report is the rate of incidental lobar and sub-lobar necrosis present in 31% of patients (n = 4), although only 1 patient (7.7%) had complete lobar necrosis. Although hypercoagulability, with resultant strokes[16,17] and myocardial ischemia,[18,19] has been described in COVID-19, no such report exists for lung necrosis. Although 3 of the 4 patients were receiving therapeutic anticoagulation before surgery, pulmonary necrosis was present and necessitated resection, indicating a microvascular disease process that may be refractory to anticoagulation. Pathology of autopsy specimens indicates that microthrombus and large-vessel thrombus were present in a cohort of patients with a median age of 73 years, and 60% of patients had more than 3 comorbidities,[5] although the rate of anticoagulation in those patients was not reported. Additional pathologic evaluation of these resected necrotic pulmonary specimens is necessary to further elucidate the mechanism of pulmonary injury in patients with COVID-19. Of note, no pulmonary necrosis was evident on preoperative imaging for any patient.

Healthcare providers are also wary of performing thoracic surgery, particularly minimally invasive surgery using insufflation, in patients with COVID-19 because of the risk of aerosolization and transmission of disease. Some surgeons have advocated the use of port-only access for minimally invasive procedures, as well as insufflation using continuous smoke/aerosol removal and filtration, and minimizing instrumentation changes.[20] For thoracotomy cases, a continuous-suction system with filtration is recommended.[20] Additionally, transmission of virus from aerosolization from a chest drain with an air leak has been anecdotally reported, with suggestions of placing a viral filter in the drainage system.[21] However, for these 13 cases that were performed at our institution, the only extra precautions used were PPE with full gowns for all personnel in the room, N95 masks worn throughout the entire procedure, and all operations performed in a negative pressure operating room. Standard postoperative chest tube management was performed without a viral filter, with no known perioperative or postoperative transmission of the SARS-CoV-2 virus to any healthcare worker.

Study Strengths and Limitations

The major strength of this series is that it is the largest case series to describe the complications of COVID-19 that require thoracic surgical intervention and to report early outcomes. This report demonstrates the feasibility of operating in patients with COVID-19 without transmission of the disease to healthcare workers. This study is limited because it is a single-institution retrospective analysis. Furthermore, data regarding the total number of patients who were evaluated for and declined for surgical intervention are not available because of the retrospective nature of this study.

CONCLUSIONS

COVID-19 can lead to thoracic complications that require surgical intervention. The indications for surgery at our institution were complex pneumothorax, pneumatocele, empyema, or hemothorax. Given the good overall survival and lack of transmission of the SARS-CoV-2 virus to health care providers, surgical intervention is feasible and safe for patients with COVID-19.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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