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.

Cardiac Surgery Outcomes in an Epicenter of the COVID-19 Pandemic

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As New York State quickly became the epicenter of the COVID-19 pandemic, innovative strategies to provide care for the COVID-19 negative patients with urgent or immediately life threatening cardiovascular conditions became imperative. To date, there has not been a focused analysis of patients undergoing cardiothoracic surgery in the United States during the COVID-19 pandemic. Therefore, we seek to summarize the selection, screening, exposure/conversion, and recovery of patients undergoing cardiac surgery during the peak of the COVID-19 pandemic. We retrospectively reviewed a prospectively maintained institutional database for patients undergoing urgent or emergency cardiac surgery from March 16, 2020 to May 15, 2020, encompassing the peak of the COVID-19 pandemic. All patients were operated on in a single institution in New York City. Preoperative demographics, imaging studies, intraoperative findings, and postoperative outcomes were reviewed. Between March 16, 2020 and May 15, 2020, a total of 54 adult patients underwent cardiac surgery. Five patients required reoperative sternotomy and cardiopulmonary bypass was utilized in 81% of cases. Median age was 64.3 (56.0; 75.3) years. Two patients converted to COVID-19 positive during the admission. There was one operative mortality (1.9%) associated with an acute perioperative COVID-19 infection. Median length of hospital stay was 5 days (4.0; 8.0) and 46 patients were discharged to home. There was 100% postoperative follow up and no patient had COVID-19 conversion following discharge. The delivery of cardiac surgical care was safely maintained in the midst of a global pandemic. The outcomes demonstrated herein suggest that with proper infection control, isolation, and patient selection, results similar to those observed in non-COVID series can be replicated.

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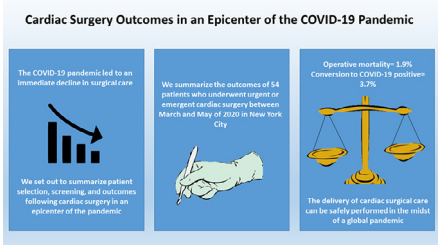

Graphical abstract showing safe delivery of surgical care during the COVID-19 pandemic

Central Message

The delivery of cardiac surgical care can be safely performed in the midst of a global pandemic with outcomes similar to those observed in non-COVID series.

Perspective Statement

During the peak of the COVID-19 pandemic, strategies to provide care for COVID-19 negative patients with urgent or immediately life threatening cardiovascular conditions became imperative. To date, there has not been a focused analysis of patients undergoing cardiothoracic surgery in the United States during the COVID-19 pandemic.

Abbreviations: COVID-19, Novel respiratory virus caused by SARS Coronavirus 2; MI, Myocardial infarction; DSWI, Deep sternal wound infection; ACGME, Accreditation council of graduate medical education; VA ECMO, Venoarterial extracorporeal membrane oxygenation

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INTRODUCTION

In December of 2019, an outbreak of a novel coronavirus disease (COVID-19) caused by SARS Coronavirus 2 (SARS-CoV-2) started in Wuhan, China.[1] On March 11, 2020, the World Health Organization officially declared COVID-19 a worldwide pandemic and many countries began to issue and enforce shelter-in-place orders. In the United States, New York State quickly emerged as the epicenter of the COVID-19 pandemic with the first confirmed diagnosis on March 1, 2020. On March 7, 2020, a state of emergency was declared by the

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governor of New York after 89 new cases were reported over a span of 6 days. To date, New York State has accounted for over 300,000+ cases, representing more than 25% of the cases across the country.[2] Hospital officials statewide were quickly burdened with the task of adapting to an evolving healthcare crisis. Intensive care units filled to capacity and step down units and operating rooms were converted into makeshift critical care areas to accommodate the rapidly increasing COVID-19 patient population, a third of whom required mechanical ventilation.[3]

Retrospective series have demonstrated operative mortality rates as high as 20% in patients undergoing elective surgery during the crisis.[4,5] Independent of COVID-19, patients requiring an urgent or emergency operation continued to exist, necessitating thoughtful triage to effectively mitigate disease in a time of limited resources and concern for exposure.[6] As the pandemic progressed, understanding the effects of potential virus exposure and transmission, operating in a time of limited resources, and the biological response to the stress of surgery in a patient with potential COVID-19 infection were some of the questions that remained largely unanswered.

At our center, an executive committee was created to develop innovative strategies to provide care for not only the new influx of COVID-19 patients, but also to addresses the needs of COVID-19 negative patients with urgent or immediately life threatening conditions. We continued to perform urgent and emergent cardiac surgical procedures by instituting a system that helped minimize operative risk and serologic conversion utilizing strict institutional perioperative safeguards. To date, there has not been a focused analysis of patients undergoing cardiothoracic surgery in the United States during the COVID-19 pandemic. We therefore seek to summarize the selection, screening, exposure/conversion, and recovery of patients undergoing cardiac surgery during the COVID-19 pandemic at a large tertiary referral center in New York City. In addition, we describe the implementation and vetting of a COVID-19 negative unit during the first wave of the pandemic.

METHODS

Patient population and data sources

This study was approved by the institutional review board of Weill Cornell Medical Center (#20-05022077) and the need for individual patient consent was waived. We retrospectively reviewed a prospectively maintained institutional database for patients undergoing urgent or emergency cardiac surgery from March 16, 2020 to May 15, 2020, encompassing the peak of the COVID-19 pandemic. Patients included in the analysis were 18 years or older, undergoing a primary cardiac surgical procedure at an 862-bed quaternary referral center in Manhattan, New York.

Data collected included patient demographics, preoperative comorbidities, functional status, and clinical characteristics including preoperative imaging, vital signs, routine diagnostic laboratory values, procedure status, intraoperative variables, postoperative morbidity, and postoperative mortality. Information related to testing for COVID-19 using polymerase chain reaction (PCR) was also collected including testing performed at external institutions, when applicable. Follow-up status and readmissions were captured through routine scheduled outpatient video-visits, and direct patient contact as needed.

Operative Criteria

Criteria for urgent and emergency operations was determined in accordance with the American College of Surgeons COVID-19 Triage Guidelines for Surgical Care.[7] Each week, a committee of surgeons from all specialties, hospital administrators, and ethicists met to determine patient status as determined by the guidelines. All urgent or emergency cases were vetted through the chairman of each department and presented before the committee for approval prior to operation.

Study outcomes and definitions

In-hospital events included: death, time to discharge, COVID-19 status on admission, re-testing for COVID-19 during admission, retesting for COVID-19 following discharge, and readmission. Postoperative complications included reoperation, myocardial infarction (defined in accordance with the Fourth Universal Definition of Myocardial Infarction[8]), permanent stroke (defined as new neurologic deficit with new changes on computed tomography or magnetic resonance imaging), new onset arrhythmia (including new atrial fibrillation, atrial flutter, ventricular tachycardia, ventricular fibrillation, and complete heart block), renal failure (defined as new dialysis, or serum creatinine rise ≥1.5x baseline), deep sternal wound infection, cardiac pacemaker implantation, respiratory failure requiring tracheostomy, and gastrointestinal complications (including prolonged ileus, acalculus cholecystitis, and mesenteric ischemia).

Statistical analysis

Preoperative demographics, imaging studies, intraoperative findings, and postoperative outcomes were reviewed. Continuous variables are expressed as a mean and standard deviation or median and interquartile range based on normality. Categorical variables are expressed as counts and percentage. When eligible, operative risk score profiles were calculated using the Society for Thoracic Surgery Adult Cardiac Surgery database version 2.9.

RESULTS

Evolving Hospital Infrastructure

The COVID-19 pandemic began with an abrupt rise in ICU hospitalizations, suppressing traditional routes of postoperative cardiac recovery. Within our hospital pre-existing ICU's, step-down units and procedural recovery areas were converted into COVID-19 (+) ICU's.[9] Cardiothoracic surgery patients were displaced into a newly created space, which had previously

functioned as a post-anesthesia care unit, and was designated a COVID-19 (−) area. This 18-bed unit consisting of 16 open beds and 2 negative pressure rooms was selected due to proximity to operating suites and accessibility. The unit accepted patients with non-COVID-related medical or surgical critical illness. Due to hospital demands in COVID-19 (+) ICU's, the newly formed COVID-19 (−) unit was initially staffed according to our institutional surge response plan.[10] The COVID-19 (−) unit team was led by a cardiothoracic attending surgeon, Accreditation Council of Graduate Medical Education (ACGME) cardiothoracic surgery fellows, ACGME general surgery residents and cardiothoracic ICU PAs. Care was delivered in shifts to provide 24 hour coverage within the guidelines of ACGME mandates. The Anesthesiologist-Intensivist, traditionally providing 24/7 oversight of the CTICU, was available for consultation as needed during the initial COVID-19 surge.

Following surgery, all patients recovered in the newly formed COVID-19 (−) ICU space. Repeat testing was performed for any patient who developed symptoms of fever, chest pain, increasing oxygen requirement, or high clinical suspicion for COVID-19. Patients remained in the COVID-19 (−) unit until the time of discharge with efforts were made to discharge patients home rather than other medical facilities in an effort to limit potential exposure at alternative facilities. In lieu of inpatient follow up appointments, virtual patient visits were conducted with in office visits limited to patients requiring physical presence such as wound issues or other complaints unable to be satisfactorily evaluated remotely.

COVID-19 Testing

SARS-CoV-2 RT-PCR (Cepheid, Sunnyvale, CA) sampling was conducted by nasal swab with 2 consecutive negative results required prior to admission into the open, general care area. Patients from outside facilities were accepted for transfer only if they had documented negative PCR testing. These patients were isolated in 1 of the 2 negative pressure rooms, retested on site and allowed out of isolation once negative testing was confirmed. Any patient testing positive during admission was immediately transferred to a COVID-19 (+) ICU within the hospital. As a result of severe shortages and limitations of testing capabilities prior to April 1, 2020, screening was performed only in patients demonstrating symptoms consistent with COVID-19. Screening criteria was expanded as testing capabilities of the hospital increased. By April 1, 2020, testing supplies were adequate for preadmission testing on all subsequent patients regardless of symptom profile. A detailed algorithm for COVID-19 testing is outlined in Figure 1.

Outcomes

Between March 16, 2020 and May 15, 2020, a total of 54 adult patients underwent a cardiac surgery compared with 162 patients during the same period one year prior representing a 62% decrease in surgical volume (Supplementary Fig. 1). Median age was 64.3 (56; 75) years. Eighteen patients were female and 36 male. A majority of patients had a history of hypertension (75.9%) and hyperlipidemia (55.6%), while congestive heart failure (5.6%) and chronic obstructive

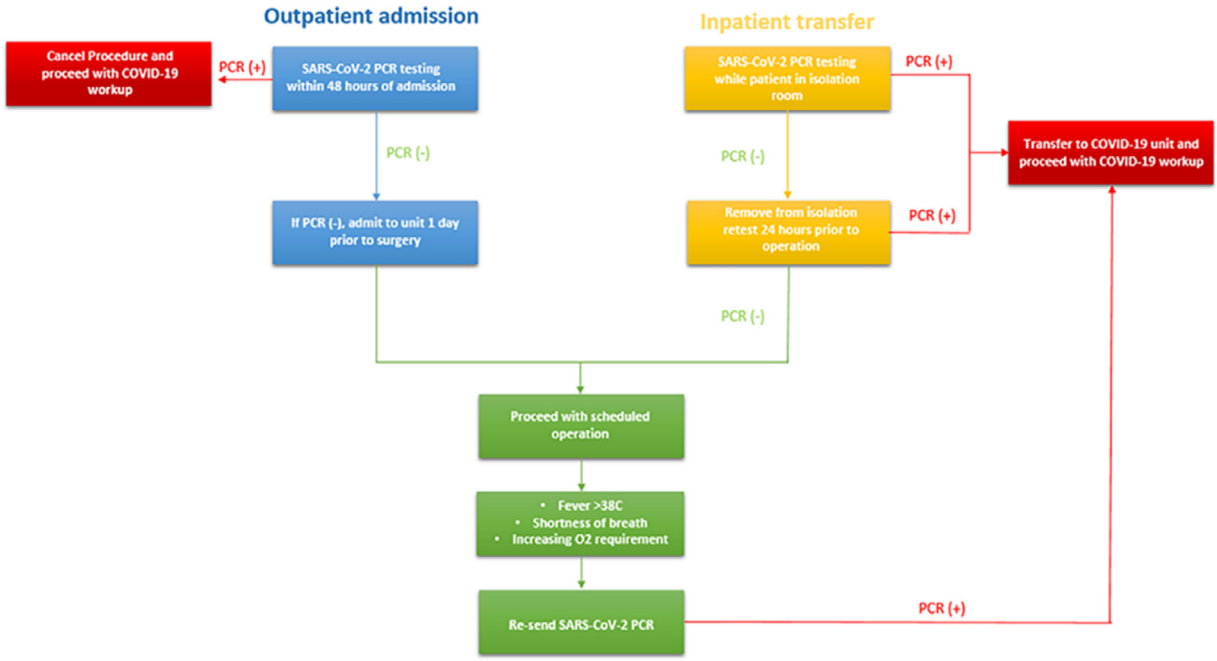

Figure 1. Screening and testing algorithm for COVID-19 for inpatient and outpatient admissions. Green arrows represent proceeding with the algorithm, red arrows represent stopping the algorithm and proceeding with further COVID-19 related workup. Abbreviations: O_2, oxygen; PCR, polymerase chain reaction; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

Table 1. Characteristics

Characteristic	(n = 54)
Age	64.3 (56.0; 75.3)
Gender	
Male	36 (66.7%)
Female	18 (33.3%)
Hypertension	41 (75.9%)
Hyperlipidemia	30 (55.6%)
Coronary Artery Disease	23 (42.6%)
Congestive Heart Failure	3 (5.6%)
Chronic Obstructive Pulmonary Disease	6 (11.1%)
Diabetes Mellitus	11 (20.4%)
Chronic Renal Insufficiency	6 (11.1%)
Cerebral Vascular Disease (prior TIA or Stroke)	10 (18.5%)
Peripheral Vascular Disease	4 (7.4%)
Connective Tissue Disorder	3 (5.6%)
Smoking	
Active	4 (7.4%)
Former	18 (33.3%)

pulmonary disease (11.1%) were less prevalent. Full preoperative patient characteristics are available in Table 1.

Five patients underwent reoperative sternotomy. Cardiopulmonary bypass was utilized in 81% of cases. A complete list of operations can be found in Table 2. All procedures were classified as urgent or emergency cardiac surgery. A total of 6 patients underwent emergency operation, 3 for acute type-A dissection, 2 for acute myocardial infarction with associated sequelae, and 1 for symptomatic pericardial effusion with tamponade physiology.

Table 2. Operations Performed

Operation	No. Performed (N = 54)
TAVR	9
Ventricular assist device	1
Mitral Valve Replacement	1
Aortic Valve Replacement	6
Coronary Artery Bypass Grafting	12
Aortic Replacement for Aneurysmal Disease	
Arch (DHCA)	1
Ascending	1
Modified Bentall	3
Valve Sparing Root Reimplantation	1
Thoracoabdominal	1
Type A Dissection	3
Adult Congenital	2
Cardiac Tumor	3
Pericardial Window	1
Combined Operations	
AVR + MV Repair	1
AVR + MVR + CABG	1
LA Mass Resection + CABG	1
Ascending + AVR	3
Valve Sparing Root Reimplantation + MV Repair	1
Arch + AVR	1
Arch + Mod. Bentall	1

Table 3. Outcomes

Outcome	No. of Events (%)
Mortality	1 (1.9)
Re-exploration for Hemorrhage	4 (7.4)
Postoperative Myocardial Infarction	0 (0.0)
New Onset Atrial Fibrillation	11 (20.4)
Pacemaker Implantation	1 (1.9)
Cerebral Vascular Accident	0 (0.0)
Tracheostomy	1 (1.9)
Acute Kidney Injury	2 (3.7)
Deep Sternal Wound Infection	0 (0.0)

A total of 11 patients (20.4%) were diagnosed with new onset atrial fibrillation, 4 required re-exploration for bleeding, 1 required tracheostomy, and 2 developed acute kidney injury that resolved prior to discharge (Table 3). Median length of hospital stay following operation was 5 days (4; 8) and 46 patients were discharged to home. There was 100% postoperative follow up by virtual or in office visits. Mean follow up was 22.9 ± 12.4 days. No patient included in this study reported COVID-19 conversion or hospitalization for COVID-19 related symptoms following discharge.

Postoperatively, two patients became COVID-19 positive. There was one operative mortality (1.9%) associated with complications attributed to an acute perioperative COVID-19 infection. The sole mortality presented as a single ventricle Fontan from an outside hospital with myocarditis of undetermined origin requiring support with venoarterial extracorporeal membrane oxygenation (VA-ECMO) for a number of weeks during the initial phase of the COVID-19 pandemic. The patient was screened twice for COVID-19 prior to ventricular assist device implantation, both results were negative. The patient expired on postoperative day one due to vasoplegia in the setting of an extreme systemic inflammatory response. Postsurgical testing revealed COVID-19 positivity at the time of death. The remaining post-surgical COVID-19 conversion occurred 5 days following an uneventful mitral valve replacement and CABG. This patient was discharged home following a prolonged nasal cannula oxygen wean, has recovered and experienced no additional sequelae.

Twenty-eight patients met criteria for risk stratification using the STS online Risk Calculator (Supplementary Table 1). Within this group, there were no mortalities and 1 reoperation for postoperative hemorrhage, hence the O/E ratio for mortality was 0.

A total of 38 patients were screened for COVID-19 prior to admission (Table 4). Two patients that tested positive for COVID-19 prior to operation were transferred to alternative intensive care units following testing. One patient died prior to operation from COVID-19 related acute respiratory distress

Table 4. SARS-CoV-2 PCR Testing

Test Group	SARS-CoV-2 PCR (−)	SARS-CoV-2 PCR (+)	Not Tested
Preoperative (n = 56)	36 (64.2)	2 (3.6)	18 (32.1)
Postoperative Inpatient (n = 54)	9 (16.7)	2 (3.7)	43 (79.6)
Postoperative Outpatient (n = 54)	1 (1.9)	0 (0.0)	53 (98.1)

syndrome. The second patient was discharged home following recovery and is scheduled for operation in the near future.

A graphical abstract presenting the safe delivery of cardiac surgical care during the height of the COVID-19 pandemic is presented in Figure 2.

DISCUSSION

This analysis reports how urgent and emergent cardiac surgical procedures were performed at a quaternary referral center in the epicenter of the pandemic during its peak. Since the onset of the pandemic, a total of 8393 patients were tested at our facility for COVID-19. There were 2345 (27.9%) positive tests with the peak of the pandemic occurring in mid-April. During this time, COVID-19 related admissions exposed a variety of unforeseen obstacles and numerous limitations. Through comprehensive and expeditious testing, we were able to identify COVID-19 positive patients prior to surgery, allowing not only for postponement of surgery, but also for the initiation of any related therapies needed. The same system of safeguards will be used in the recovery phase of the pandemic even as elective surgery is resumed.

There is limited data with respect to cardiac surgery outcomes during the COVID-19 pandemic. A single institution retrospective analysis from China described a 10% COVID-19 conversion rate with an associated 27% mortality in patients undergoing cardiothoracic surgery.[5] Despite our ability to maintain a lower conversion rate amongst our population, we found a similar mortality rate in those who converted to COVID-19 positive status following operation. To be sure, infection with SARS-CoV-2 has proven to be consequential in patients undergoing surgery and is further complicated by the fact that patients undergoing cardiac surgery frequently exhibit signs that mimic those of acute COVID-19 as part of the normal postoperative inflammatory response. Currently, an international multicenter cohort study is investigating the impact of COVID-19 on surgical outcomes (NCT04323644). The results of this study, however, are not anticipated until late 2020, and is investigating several surgical specialties.

The COVID-19 pandemic has had a profound impact on the delivery of surgical care worldwide. Using a Bayesian beta-regression model, a recent report in the *British Journal of Surgery* by the CovidSurg Collaborative estimates that over 28 million operations would be cancelled or postponed during the 12-week peak of the pandemic. In the United States, the model estimated a cancellation or postponement of over 340,000 cases per week. The authors conclude that if countries make a dedicated effort to increase surgical volume by 20% postpandemic, it will take a median of 45 weeks to clear the backlog of cases.[11] A similar state of affairs in present in cardiac surgery. An international survey of 60 hospitals based in 19 countries representing over 600 cardiac surgeons found a median reduction in case volume of 50%-75%, with a majority of centers restricting operative activity to only urgent or emergency surgeries. In fact, 5% of respondents reported cancelling emergency surgeries for some period of time.[12] This is further compounded by patient reluctance to seek care during the

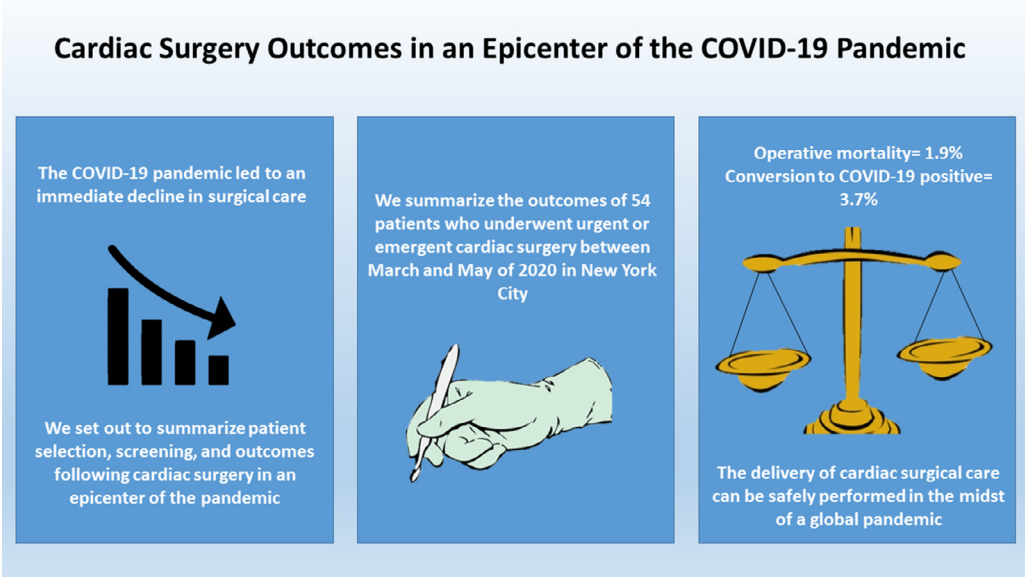

Figure 2. Graphical abstract showing safe delivery of surgical care during the COVID-19 pandemic.

pandemic. In New York City, for example, a significant drop in surgical volume for acute type A aortic dissection was noted when comparing pre- and post-COVID-19 eras (12.8 ± 4.6 cases/month pre-COVID vs 3.0 ± 1.0 cases post-COVID, representing a 76.5% decrease in volume). This decrease coincided with an increase in at-home deaths, suggesting that patients were avoiding hospitals secondary to the widespread fear induced by the COVID-19 pandemic.[13]

While elective surgical procedures can be safely postponed, delay for urgent or emergency surgeries may result in life threatening outcomes. Compared to historical controls, delay in patient presentation and a marked reduction in primary PCI have been reported during the COVID-19 pandemic, which has led to an overall increase in the progression of disease at the time of evaluation.[14] Similarly, we observed that symptomatic cardiac patients avoided hospitals out of fear of exposure to COVID-19 and this resulted in progression of disease to late stages and decompensated states. Even during a pandemic, severe cases such as type A dissections, postinfarction ventricular septal defects, and symptomatic cardiac disease cannot be safely delayed. It is imperative to be able to safely operate on these patients while minimizing their risk of exposure to COVID-19.

With many regions around the world now starting to see the number of cases plateau or decline, there is an urgent need to address how to resume cardiac surgery in a safe manner with strict and validated protocols. Recently, an international consortium of cardiac surgeons published guidance for the safe resumption of cardiac surgery during the COVID-19 pandemic. The authors recommended early resumption of cardiac surgical services when able, institutional triggers for scaling cardiac volume up or down depending on COVID-19 admission status, triaging of cases as driven by a multidisciplinary heart team, preoperative screening of all patients for infection with SARS-CoV-2 and the utilization of virtual care postdischarge.[6] Additionally, the Society of Thoracic Surgeons COVID-19 Task Force recently released a guidance statement for increasing the delivery of cardiac surgery. The authors advocate for continuing to address urgent and emergency surgeries with a graded increase in elective case volume. Furthermore, the task force recommends routine testing via nasopharyngeal swab, and delaying of any confirmed or suspected COVID-19 positive case by at least 2 weeks when feasible.[15] Other collaborative statements have echoed these recommendations.[16]

While concern about subsequent waves of the virus remain, we hope that our experience may lend credence to the idea that urgency or emergency cardiac surgery can be safely and effectively performed in cardiac centers across the globe using thoughtful planning and adherence to protocols. As testing and treatment paradigms for COVID-19 continue to expand and the resurgence of cardiac surgery intensifies, throughout attention must be placed on prioritizing the patient with late stage disease whose treatment has been delayed by the infection with SARS-CoV-2.

Limitations of this study include the small sample size and insufficient means to preoperative testing during the early phases of the pandemic. Considerations should also include the expansive hospital infrastructure in which this study took place. Similar results may not be translatable for smaller institutions in which more stringent limitations on available resources exist.

CONCLUSION

The delivery of cardiac surgical care can be safely performed in the midst of a global pandemic. The outcomes demonstrated herein suggest that with proper infection control, isolation, and patient selection, outcomes similar to those observed in non-COVID series can be replicated. Moving forward, validated protocols will need to be further developed and widely adopted as we transition out of the valley and back towards our "new normal."

ACKNOWLEDGMENTS

None.

PATIENT CONSENT

This study was approved by the institutional review board of Weill Cornell Medical Center (#20-05022077) on June 2, 2020 and the need for individual patient consent was waived.

SUPPLEMENTARY MATERIAL

Scanning this QR code will take you to the article title page to access supplementary information.

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