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# The Surge After the Surge: Cardiac Surgery Post–COVID-19



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**Background.** The coronavirus disease 2019 (COVID-19) pandemic has dramatically reduced adult cardiac surgery case volumes as institutions and surgeons curtail nonurgent operations. There will be a progressive increase in deferred cases during the pandemic that will require completion within a limited time frame once restrictions ease. We investigated the impact of various levels of increased postpandemic hospital operating capacity on the time to clear the backlog of deferred cases.

**Methods.** We collected data from 4 cardiac surgery programs across 2 health systems. We recorded case rates at baseline and during the COVID-19 pandemic and created a mathematical model to quantify the cumulative surgical backlog based on the projected pandemic duration. We then used the model to predict the time required to clear the backlog depending on the level of increased operating capacity.

**Results.** Cardiac surgery volumes fell to 54% of baseline after restrictions were implemented.

Assuming a service restoration date of either June 1 or July 1, we calculated the need to perform 216% or 263% of monthly baseline volume, respectively, to clear the backlog in 1 month. The actual duration required to clear the backlog highly depends on hospital capacity in the post-COVID period, and ranges from 1 to 8 months, depending on when services are restored and the degree of increased capacity.

**Conclusions.** Cardiac surgical operating capacity during the COVID-19 recovery period will have a dramatic impact on the time to clear the deferred cases backlog. Inadequate operating capacity may cause substantial delays and increase morbidity and mortality. If only pre-pandemic capacity is available, the backlog will never clear.

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The coronavirus disease 2019 (COVID-19) pandemic has resulted in dramatically lower adult cardiac surgery case volumes, because institutions and surgeons are following state and federal guidelines to curtail nonurgent operations. There will be a progressive increase in deferred cases during the pandemic that will require completion within a limited time frame once pandemic restrictions ease, to avoid excess morbidity and mortality.<sup>1-3</sup> By definition, programs will have to achieve higher daily case rates than before the pandemic to service the excess demand. The postpandemic surge in adult cardiac surgery could overwhelm current hospital resources without proper planning.

## Patients and Methods

### Study Population and Data Collection

Data were collected from 4 institutions across 2 health systems. Each system included 2 large academic centers and 2 affiliated community cardiac surgery programs. First, we calculated a combined baseline case rate across centers, before the pandemic, by quantifying all cases done from January 2019 to February 29, 2020. Inclusion criteria included any adult cardiac surgery case performed in the operating room with a cardiac surgeon as primary or co-surgeon. Heart and lung transplant, ventricular assist device, and transcatheter aortic and mitral valve replacements were included. Primary extracorporeal membrane oxygenation cases and pediatric cases were excluded. Next, we calculated the combined rate of cases during the early part of the pandemic. Raw data were collected from March 16 through April 12 and were used to extrapolate a new pandemic surgical case rate. March 16 was the day after the state of emergency was declared in the State of Maryland. We calculated the

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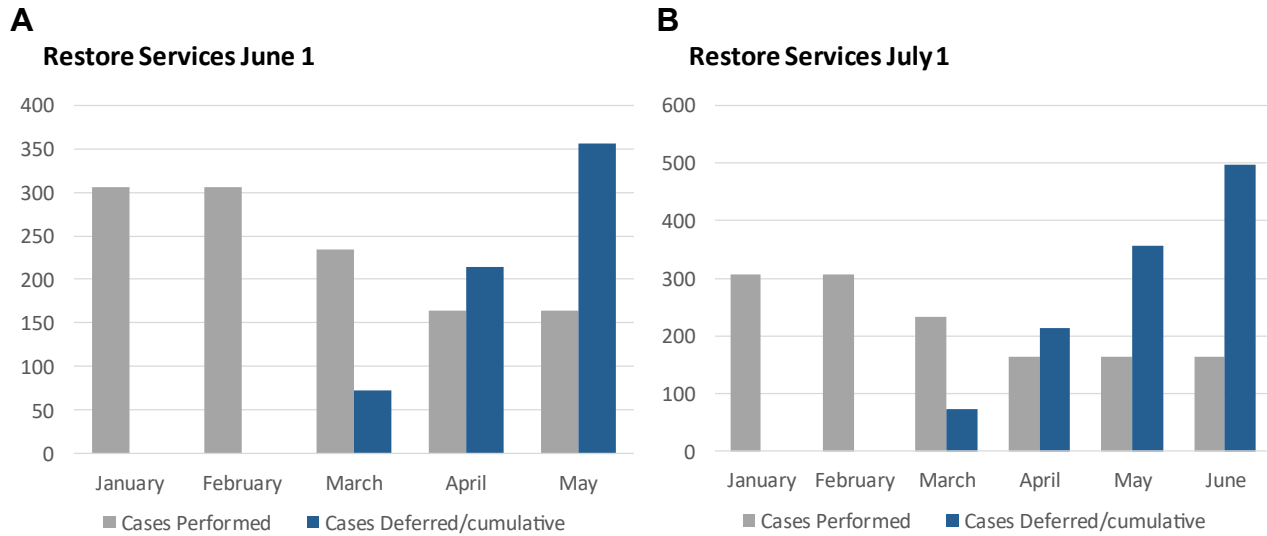


Figure 1. Pandemic-related drop in cardiac surgical cases and accrual of deferred cases based on duration of pandemic until (A) June 1 and (B) July 1.

number of patients who would have surgery deferred during the pandemic, and the length of time necessary to service the backlog in a timely fashion once restrictions were lifted.

### Mathematical Modeling

Mathematical models were used to investigate the impact of the date when restrictions are lifted, and variable levels of hospital operating capacity on the time that would be required to address the backlog. To calculate the current backlog (B) on any given day (T), we developed the equation  $B = (R_0 - R_p)(T - T_0)$ . This is the difference in the daily case rates multiplied by the number of days that difference had existed. T1 was then defined as the day that restrictions were eased and full operating capacity regained. Next, the number of operating days necessary to perform all backlogged cases, defined as backlog time (BT), was calculated. The model was designed to predict the length of time required to clear the backlog based on the amount of extra operating capacity a hospital could achieve. Our prediction model defined T0 as the day the pandemic began, and T1 as the day restrictions were lifted. Each hospital's postpandemic daily case rate would be defined by an acceleration factor (a) multiplied by the

original prepandemic case rate, R0. The time required to clear the backlog of cases, BT, was then calculated; BT was defined by the equation  $BT = (1 - R_p/R_0)(T_1 - T_0) / (a - 1)$ . The acceleration factor (a) represented how much surgical throughput a program could achieve above baseline. This factor would have to be greater than 1 to incorporate some amount of deferred cases into the operating schedule in addition to baseline cases.

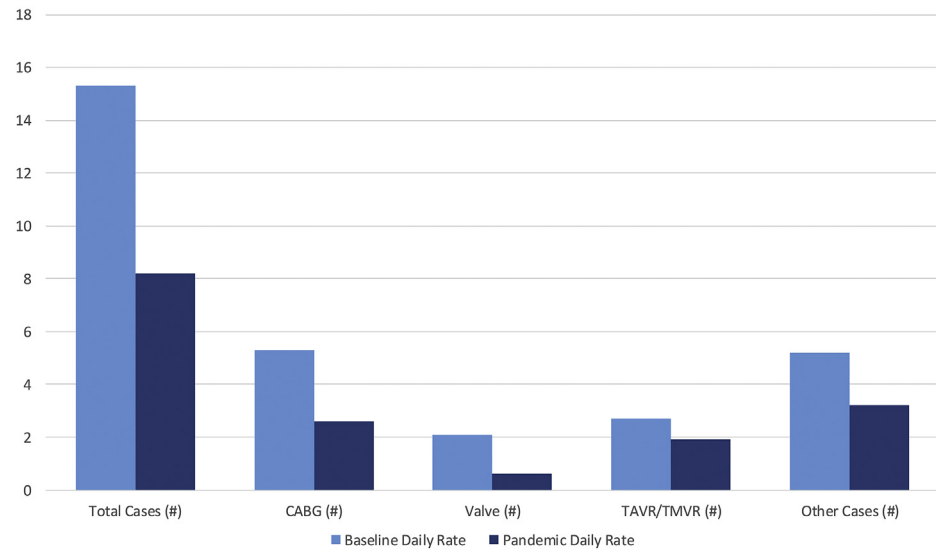
### Results

Cases were initially curtailed in early to mid-March 2020 and then more drastically in April as recommendations to postpone all but emergency operations became stronger. Baseline total case rate for the 4 combined programs was 306 adult cardiac surgery cases per month. During the pandemic, that rate initially fell to 234, and then to 164 cases per month once full restrictions were implemented (54% of normal). During this time, the number of deferred cases would be estimated to grow to 356 by June 1, and 498 by July 1. This represents 216% to 263% of normal average monthly volume, depending on the duration of the pandemic (Figure 1). The daily case rates were also calculated. We assumed 20 operative weekdays per

Table 1. Baseline and Pandemic Case Volumes for Total Cases, Coronary Artery Bypass Grafting, Valve Replacement, Transcatheter Aortic and Mitral Valve Replacements, and Other Cases

Time Period	Total Cases, n	Coronary Artery Bypass Grafting, n	Valve Replacement, n	Transcatheter Aortic and Mitral Valve Replacements, n	Other Cases, n
Baseline (January 1, 2019 to February 29, 2020)	4292	1491	583	752	1466
Pandemic (March 15, 2020 to April 12, 2020)	164	51	11	38	64
Baseline daily rate	15.3	5.3	2.1	2.7	5.2
Pandemic daily rate	8.2	2.6	0.6	1.9	3.2

Figure 2. Baseline versus pandemic case rates. (CABG, coronary artery bypass grafting; TAVR/TMVR, transcatheter aortic and mitral valve replacements.)



month. For the combined health systems, the average daily case rate before the pandemic, defined as  $R_0$ , was 15.3. The daily case rate during the pandemic, defined as  $R_p$ , was calculated to be 8.2 (Table 1). We also calculated the baseline and pandemic daily case rates for 3 broad categories of cases, including coronary artery bypass grafting (CABG), open valve surgery, and transcatheter aortic and mitral valve replacements (Figure 1). Combined CABG/valve cases were counted as CABG because we thought that the patient’s coronary disease would often dictate more urgent triage (Figure 2). Isolated valve cases were more likely to be deferred than would patients with isolated or concomitant coronary disease. Transcatheter cases were treated differently between health systems. One system’s transcatheter case rate fell from 34/month to 8/month, whereas the other system increased their transcatheter cases from 21/month to 32/month. This equated to approximately a 75% decrease in one system’s transcatheter cases and a 30% increase within the neighboring system. This differential treatment of transcatheter cases partially mitigated the overall backlog accumulation. The CABG and valve patients were triaged similarly by the health systems; these case rates fell by 50% and 71%, respectively.

Next, we used our mathematical model to predict the number of cardiac surgery cases deferred during the pandemic and the length of time required to operate on the backlog, dependent on the amount of increased operating capacity the institutions could achieve. Time to clear the backlog, BT, was calculated using our mathematical model (Figure 3). This was considered for the possibility of restored services on June 1 or July 1 with varied levels of case capacity (Figure 4). Assuming services were restored on June 1, the backlog could be cleared between 1 and 6 months, depending on the degree of increased capacity. If services resumed on July 1, the cardiac surgery backlog would be estimated to take between 2 and 8 months to clear according to the increased capacity achieved. Progressively increasing the

operating capacity had a dramatic effect on reducing the time to clear the backlog. If capacity is not increased above baseline (acceleration factor = 1.0), the backlog will never be cleared.

**Comment**

In response to the COVID-19 pandemic, adult cardiac surgery programs have dramatically curtailed operating activity, limiting cases to urgent and life-threatening emergencies. This slowdown has resulted in a growing backlog of adult cardiac surgery cases that will require surgical therapy in a finite time frame to improve quality of life and survival. Our study analyzed the deliberate deceleration in adult cardiac surgery cases that has occurred at the 2 busiest cardiac surgical programs in Maryland in response to the COVID-19 pandemic. We observed a 54% drop in cardiac surgical volume and subsequently a backlog that would require a monthly

$$a) B = (R_0 - R_p) (T - T_0)$$

$$b) BT = (1 - R_p/R_0) (T_1 - T_0) / (a - 1)$$

Figure 3. Equations for (a) calculating accumulated backlog of cases and (b) days required to clear the backlog, depending on the increased capacity achieved (acceleration factor): a)  $B = (R_0 - R_p) (T - T_0)$ ; b)  $BT = (1 - R_p/R_0) (T_1 - T_0) / (a - 1)$ , where B = backlog;  $R_0$  = daily case rate before the pandemic;  $R_p$  = daily case rate during the pandemic;  $T_0$  = day the pandemic began; T = any given day of the pandemic;  $T_1$  = day restrictions are lifted and full operating resumes; BT = backlog time or time required to operate on all deferred cases; and a = acceleration factor.

**A** Restore services June 1

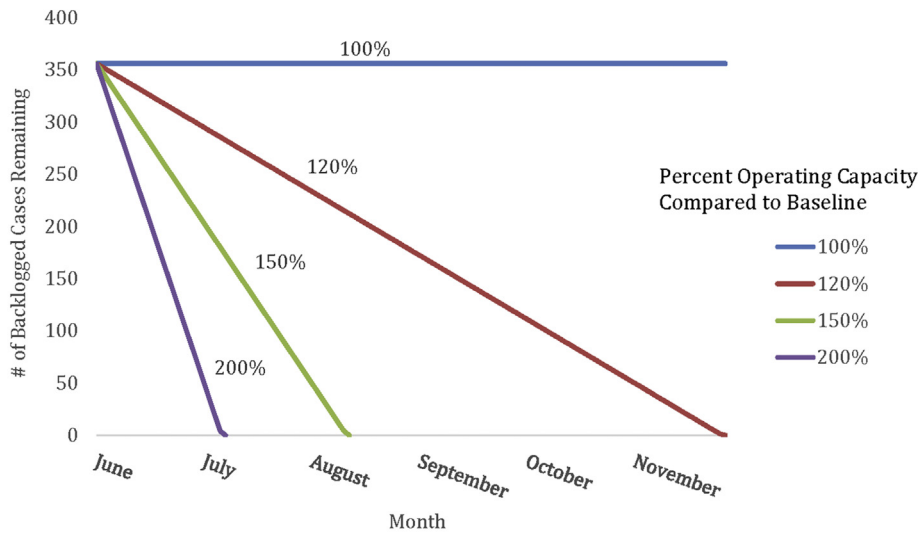
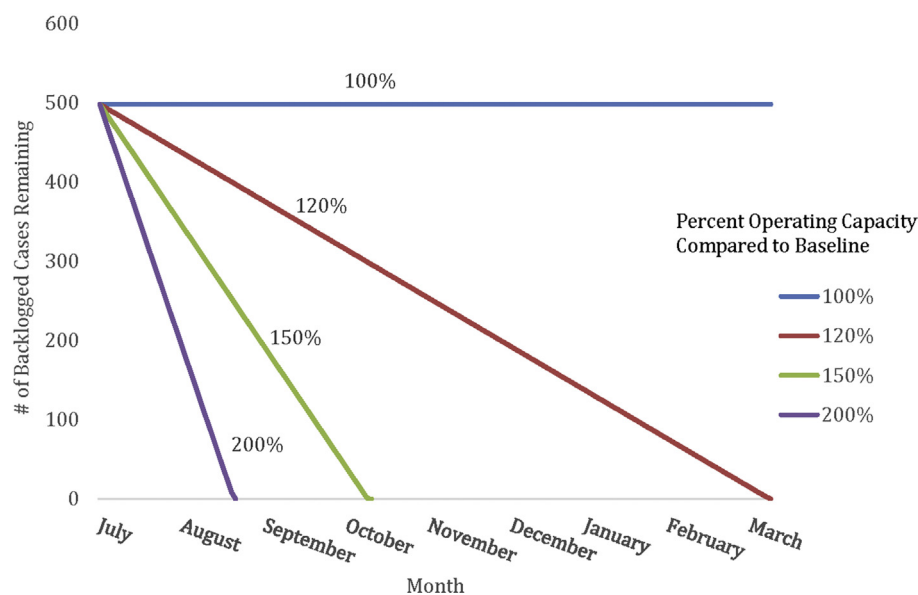


Figure 4. Time estimated to clear backlog based on variable levels of increased operating capacity achieved for services restored: (A) June 1, and (B) July 1.

**B** Restore services July 1



operating volume of 216% to 263% of baseline. Because this would be challenging to accomplish in 1 month, we predicted that the amount of time necessary to clear the backlog would range from 1 to 8 months based on varied estimates of postpandemic increased operational capacity.

Our data further suggest that deferred cardiac patients were triaged differently during the pandemic and that the composition of the waiting list is directly related to the triaging mechanism. As expected, isolated valve patients were preferentially deferred compared with patients with any coronary artery disease. We were surprised to see the differences in transcatheter case triage between the 2

systems. One system deferred most transcatheter cases whereas the other increased their rate, mainly transcatheter aortic and valve replacement cases. Although our data did not include reasons for triage decisions, this may have been due to differing thresholds for observing patients with severe aortic stenosis and uncertainty regarding best practice when deferring cardiac services.

Others have attempted to characterize the needs for surgical services after natural disasters by establishing a baseline surgical rate and then examining the incidence of injury during a disaster.<sup>4</sup> A study of the Nepal earthquakes in 2015 demonstrated an acute need for surgical therapy that was more than double the annual Nepalese

operating capacity, highlighting the need to be able to increase surgical capacity at critical times. Another study focused on the aftermath of Hurricane Charley and found a 32% increase in adverse medical outcomes for patients with chronic medical conditions related to both increased demand and shortfalls in care delivery.<sup>5</sup> Similar to our investigation, these studies focused on increased health care demand after unpredictable events. Our analysis differed because we analyzed the effect of an unexpected viral pandemic that necessitated a nearly 50% decline in surgical volume followed by an anticipated surge in surgical demand. Our study is novel in that we prospectively attempted to predict system capacity needs to service the anticipated surgical surge. This will require local hospitals and health systems to examine capacity, set priorities, and plan for adequate hospital capacity to service the backlog of cardiovascular patients.<sup>6,7</sup> The global cardiac surgery response after COVID-19 will be complicated by prior exhaustion of hospital supplies and human resources from the pandemic, and competition for resources and operating room availability with other surgical and medical subspecialties, which will also have backlogs. The recently published joint statement from the American College of Surgeons and others<sup>8</sup> provides guidance on when to reopen operating room capacity safely and includes recommendations for testing, personal protective equipment, and case prioritization. We believe that it will be important to maintain an incident command approach during the late phases of the COVID-19 epidemic as we transition to reestablishing, and increasing, our prepandemic workflow. Planning should begin now; crucially, it should prioritize patients with considerable risks arising from delayed operations. The risks of deferring needed cardiac treatment were previously demonstrated. Reported mortality rate while waiting for surgical or transcatheter aortic valve replacement can be as high as 3.7% at 1 month and 11.6% at 6 months.<sup>2</sup> For patients awaiting coronary surgery, median waiting list mortality rates of 2.6%/month have been reported, with mortality risk increasing 11%/month. In addition, 12% of patients experienced a myocardial infarction while on the waiting list.<sup>1,3</sup>

We have attempted to estimate the resources required in planning for the postpandemic surge in adult cardiac surgical volume. The capacity estimates for a given health system would depend on the percent increase in productivity targeted after the pandemic. By using our mathematical model, a health system could predict the time required for servicing the surgical backlog and adjust operating capacity accordingly. Actualizing a plan to increase capacity may occur gradually, and this will further increase waiting time for deferred patients. Increasing capacity will also require proportional adjustments in resources such as operating rooms, intensive care unit and telemetry beds, and provider staff. For most hospitals, operating room time is the most expensive resource. Consequently, increasing intensive care unit and telemetry capacity to avoid operating room holds and cancellations is likely the most cost-effective approach to achieving increased throughput. The number of

additional beds, nurses, and advanced practice providers needed can be calculated according to baseline resources. Maximizing efficiency through early telemetry discharge, decreasing intensive care length of stay, level loading elective cases in the operating room, temporarily altering staffing models, and staggering cases can help increase throughput capacity.<sup>9,10</sup> Another possible solution is to relocate some noncardiac surgical patients temporarily to other facilities within a health system. In fact, maintaining the incident command center set up by many hospitals and using some of the same workforce and bed solutions employed during the pandemic may be valuable in delivering critical cardiac services in a timely fashion.

Our analysis has several limitations. First, we assumed that historical rates of surgery will accurately predict future rates. This may be incorrect for several reasons. During the pandemic, patients may be treated with alternative medical and interventional therapy, obviating the need for surgery. Patients treated medically with symptomatic relief may decide not to pursue more aggressive treatment. Other patients may be reluctant to incur out-of-pocket costs during this time of financial difficulty. In addition, there will unfortunately be some degree of attrition of patients from cardiovascular and COVID-19-related mortality. The pent-up demand could also accrue more slowly than calculated. Cardiac surgeons sit at the bottom of a virtual funnel that begins with patients seeking medical care, referral to a cardiologist, diagnostic testing, and finally evaluation for surgery. Each step along this pathway will be delayed during the pandemic, and likely for some time afterward. Delays would function as a governor on the acceleration of postpandemic cardiac surgical demand. Nevertheless, our study provides concerning data delineating a large group of patients with surgical-level cardiovascular disease whose treatment has been necessarily deferred. Our hope is that our modeling can be used to calculate the productivity increase necessary to treat patients in an acceptable time frame. Further study could help better define the overall effects of a pandemic on the care of cardiovascular patients.

Although challenging and costly, early postpandemic operating capacity will need to be greater than the original daily capacity to satisfy the pent-up surgical demand. Not planning for postpandemic volume could result in a second wave of non-COVID-19 cardiovascular mortality.

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