Cardiovascular procedural deferral and outcomes over COVID-19 pandemic phases: A multi-center study

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Background The COVID-19 pandemic has disrupted routine cardiovascular care, with unclear impact on procedural deferrals and associated outcomes across diverse patient populations.

Methods Cardiovascular procedures performed at 30 hospitals across 6 Western states in 2 large, non–profit healthcare systems (Providence St. Joseph Health and Stanford Healthcare) from December 2018-June 2020 were analyzed for changes over time. Risk-adjusted in-hospital mortality was compared across pandemic phases with multivariate logistic regression.

Results Among 36,125 procedures (69% percutaneous coronary intervention, 13% coronary artery bypass graft surgery, 10% transcatheter aortic valve replacement, and 8% surgical aortic valve replacement), weekly volumes changed in 2 distinct phases after the initial inflection point on February 23, 2020: an initial period of significant deferral (COVID I: March 15-April 11) followed by recovery (COVID II: April 12 onwards). Compared to pre-COVID, COVID I patients were less likely to be female ($P = .0003$), older ($P < .0001$), Asian or Black ($P = .02$), or Medicare insured ($P < .0001$), and COVID I procedures were higher acuity ($P < .0001$), but not higher complexity. In COVID II, there was a trend toward more procedural deferral in regions with a higher COVID-19 burden ($P = .05$). Compared to pre-COVID, there were no differences in risk-adjusted in-hospital mortality during both COVID phases.

Conclusions Significant decreases in cardiovascular procedural volumes occurred early in the COVID-19 pandemic, with disproportionate impacts by race, gender, and age. These findings should inform our approach to future healthcare disruptions. (Am Heart J 2021;241:14–25.)

In 2020, rapid spread of the novel coronavirus (SARS-CoV-2)[1] forced hospitals across the world to triage medical procedures in an effort to flatten the COVID-19 growth curve. In mid-March of 2020, shelter-in-place orders were instituted across the United States. Professional society guidelines[2] and federal mandates[3,4] recommended deferral of non–urgent procedures at scale, both to conserve resources and to prevent patients from unnecessary risk of exposure to the virus.[5] Many cardiovascular procedures were postponed, permitting only those performed on an urgent basis, with unclear impact on diverse patient populations.

Understanding how large-scale procedural deferral was implemented across patient populations and whether any associated adverse outcomes occurred is vital to strategizing our approach to care delivery with future major healthcare disruptions. In this multi-center study, we examined changes in cardiovascular procedural volumes; changes in patient demographics, acuity, and complexity of procedures; relationships between procedure deferral and local COVID-19 burden; and patient outcomes over time for both percutaneous and

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Abbreviations: CABG, coronary artery bypass graft; CC, complication or comorbidity; CPT, Current Procedural Terminology; ICD-10, International Statistical Classification of Diseases and Related Health Problems, Tenth Revision; LOS, length of stay; MCC, major complication or comorbidity; MS-DRG, Medicare Severity-Diagnosis Related Groups; NSTE-ACS, Non–ST elevation acute coronary syndrome; PCI, percutaneous coronary intervention; SAVR, surgical aortic valve replacement; SIHD, stable ischemic heart disease; STEMI, ST-elevation myocardial infarction; TAVR, transcatheter aortic valve replacement.

Submitted March 22, 2021; accepted June 21, 2021

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0002-8703
Published by Elsevier Inc.

https://doi.org/10.1016/j.ahj.2021.06.011

open treatment of coronary artery and aortic valve disease.

Methods

All patients who underwent percutaneous coronary intervention (PCI), coronary artery bypass graft (CABG) surgery, transcatheter aortic valve replacement (TAVR), and/or surgical aortic valve replacement (SAVR) from December 02, 2018 to June 28, 2020 at 1 of 30 hospitals across 6 states (Alaska, Washington, Montana, Oregon, California, Texas) in 2 large, non–profit healthcare systems (Providence St. Joseph Health [PSJH, with hospitals across all states] or Stanford Healthcare System [SHC, with hospitals throughout Northern California]) were included in this study. Data from PSJH were obtained from the Microsoft Azure cloud data warehouse, which pulls data from the EPIC and MEDITECH electronic health record systems that are in use across all PSJH hospitals. Data from SHC were obtained from the STAnford Research Repository (STARR) platform, which pulls data from the EPIC electronic health record system. Data from both systems were merged manually in Excel. Whereas *International Classification of Diseases, Tenth Revision, Clinical Modification* (ICD-10-CM) and *Current Procedural Terminology* (CPT) codes were used to identify all inpatient and outpatient procedures and indications for treatment, *Medicare Severity-Diagnosis Related Groups* (MS-DRGs) were used to categorize treatment approaches by procedural complexity (Supplemental Tables I and II). This study was approved by the PSJH Institutional Review Board and the Stanford University Institutional Review Board, with waiver of informed consent.

Statistical analyses

The primary outcome was change in weekly volume of procedures (aggregate, and for each individual procedure: PCI, CABG surgery, TAVR, and SAVR) before and after the pandemic onset. Secondary outcomes included changes in patient demographics and comorbidities, proportion of procedures performed as an outpatient, acuity of indication for PCI (ST-elevation myocardial infarction [STEMI], non–ST-elevation acute coronary syndrome [NSTE-ACS], or stable ischemic heart disease [SIHD]), procedural complexity (defined as with/without a complication or comorbidity [CC] or major complication or comorbidity [MCC] per MS-DRG coding), and in-hospital outcomes (mortality and length of stay [LOS]). In-hospital mortality was obtained by either date of death prior to discharge or discharge status as expired.

Categorical data are presented as frequencies (percentages). Numerical data are presented as mean (SD) or median (interquartile range [IQR]), as appropriate. Income quartiles and education categories were calculated based on a patient's zip code from U.S. Census data. The Great Circle Distance formula[6] was used to calculate distance from a patient's home to the nearest hospital in the study, using latitude and longitude associated with each zip code. Long-distance travel was defined as farther than the third quartile of the distance distribution (31 miles). COVID-19 case burden was obtained by matching facility zip codes to corresponding publicly available, county-level COVID-19 data and calculating mean COVID-19 cases for each county according to relevant date ranges normalized to county population.[7] Multivariable logistic regression was performed to evaluate mortality, with adjustment for demographic variables including age, sex, race, ethnicity, state, distance from hospital, income quartile, education, insurance type, inpatient/outpatient status, as well as baseline comorbidities listed in Table I. To account for potential hospital variation, we also evaluated patient outcomes by taking hospital as a random effect in a mixed model.

For procedural complexity and mortality analyses, combination procedures were reassigned to 1 of the 4 primary procedure categories based on clinical likelihood of the "culprit" procedure. For example, we assigned mortality from a combined TAVR/SAVR procedure to the TAVR category as we assumed that TAVR was the initial (primary) procedure and SAVR was subsequently required for complication. PCI/CABG surgery combination procedures were assigned to the PCI category. SAVR procedures involving CABG surgery or PCI were assigned to the SAVR category.

To understand the magnitude of procedural deferral, we identified the first inflection point and nadir by fitting the weekly case rates over time using loss functions to smooth the time series curve. The time break points and slopes were then defined using segmented regression. To understand differences in clinical demographics and outcomes of patients who had their procedure during peak COVID-19 deferral, we chose a 4-week period surrounding the nadir (March 29, 2020) for all procedures combined, with COVID I defined as March 15, 2020 to April 11, 2020. The beginning of the COVID I period also corresponded to the release of federal mandates and professional society recommendations for procedural deferral. We defined pre-COVID as all dates from December 2018 until COVID I, and COVID II as all dates after COVID I, respectively. Trends among the 3 COVID-19 periods were compared using univariate $\chi 2$, Fisher exact, or Kruskal-Wallis tests for each variable, as appropriate. Percentage change in procedural volume during the different phases was calculated as the relative difference in mean weekly volume for each period divided by the mean weekly volume during the pre-COVID period. There was a 0.5% to 3% missing rate for race, ethnicity, income, education, distance from nearest hospital, and insurance. *P*-values <.05 were considered statistically significant for primary comparisons. For sub-group analyses, lower *P*-values were considered statistically

Table 1. Baseline patient characteristics by COVID-19 phase

Variable	Pre-COVID (*n* = 31,143)	COVID I (*n* = 1,056)	COVID II (*n* = 3,953)	*P*-value
Total procedure volume				.007
PCI[†]	21508 (69)	695 (66)	2689 (68)	
CABG surgery[*]	4133 (13)	151 (14)	513 (13)	
TAVR[§]	3051 (9.8)	118 (11)	458 (12)	
SAVR[‡]	2451 (7.9)	92 (8.7)	293 (7.4)	
Age, years	69 (61-77)	67 (59-76)	69 (61-77)	<.0001
Male	22291 (72)	815 (77)	2856 (72)	.0003
Race				.019
White	24782 (81)	842 (82)	3183 (83)	
Asian	1708 (5.6)	40 (3.9)	179 (4.7)	
Black	767 (2.5)	20 (2.0)	93 (2.4)	
Native American	484 (1.6)	25 (2.4)	55 (1.4)	
Other	2734 (9)	96 (9.4)	335 (8.7)	
Ethnicity				.074
Hispanic	2958 (10)	104 (10)	331 (8.7)	
Non–Hispanic	27264 (90)	907 (90)	3484 (91)	
Long-distance travel[||]	7838 (25)	264 (25)	957 (24)	.420
Median income quartile				.883
Q1	7542 (25)	238 (24)	975 (25)	
Q2	7610 (25)	260 (26)	933 (24)	
Q3	7569 (25)	250 (25)	964 (25)	
Q4	7575 (25)	258 (26)	964 (25)	
Education				
Eighth grade	5 (3-8)	5 (3-8)	5 (3-8)	.083
High school	23 (16-28)	23 (16-29)	23 (16-28)	.349
College or higher	31 (20-45)	31 (20-45)	32 (21-45)	.297
State				<.0001
Alaska	1202 (3.9)	54 (5.1)	185 (4.7)	
California	12537 (40)	447 (42)	1556 (39)	
Montana	1477 (4.7)	47 (4.5)	195 (4.9)	
Oregon	3383 (11)	100 (9)	460 (12)	
Texas	2310 (7.4)	53 (5.0)	157 (4.0)	
Washington	10234 (33)	355 (34)	1400 (35)	
Insurance				<.0001
Government	864 (2.8)	47 (4.5)	147 (3.7)	
Medicaid / low income	2554 (8.2)	98 (9.3)	306 (7.8)	
Medicare	18634 (60)	557 (53)	2369 (60)	
Private	8162 (26)	323 (31)	1003 (26)	
Self-pay	413 (1.3)	16 (1.5)	62 (1.6)	
Other	377 (1.2)	10 (1.0)	45 (1.1)	
Outpatients	7720 (25)	202 (19)	956 (24)	.0001
Baseline comorbidities				
Hypertension	25733 (83)	855 (81)	3283 (83)	.283
Hypercholesterolemia	23858 (77)	808 (77)	3054 (77)	.656
Diabetes	5115 (16)	183 (17)	650 (16)	.737
Prior MI	6537 (21)	229 (22)	842 (21)	.790
CVD	3327 (11)	103 (10)	407 (10)	.496
PAD	3989 (13)	120 (11)	517 (13)	.328
CHF	10789 (35)	400 (38)	1466 (37)	.001
Prior PCI	774 (2.5)	26 (2.5)	89 (2.3)	.670
Prior CABG	8256 (27)	252 (24)	1028 (26)	.135

Data presented as *n* (%) of patients or median (IQR)

Abbreviations: CABG, coronary artery bypass graft; CHF, congestive heart failure; COVID I, coronavirus disease 3/15/20 to 4/11/20; COVID II, coronavirus disease after 4/12/20; CVD, cerebrovascular disease; MI, myocardial infarction; PAD, peripheral artery disease; PCI, percutaneous coronary intervention; Q, quarter; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic replacement

[*] PCI / PCI + CABG

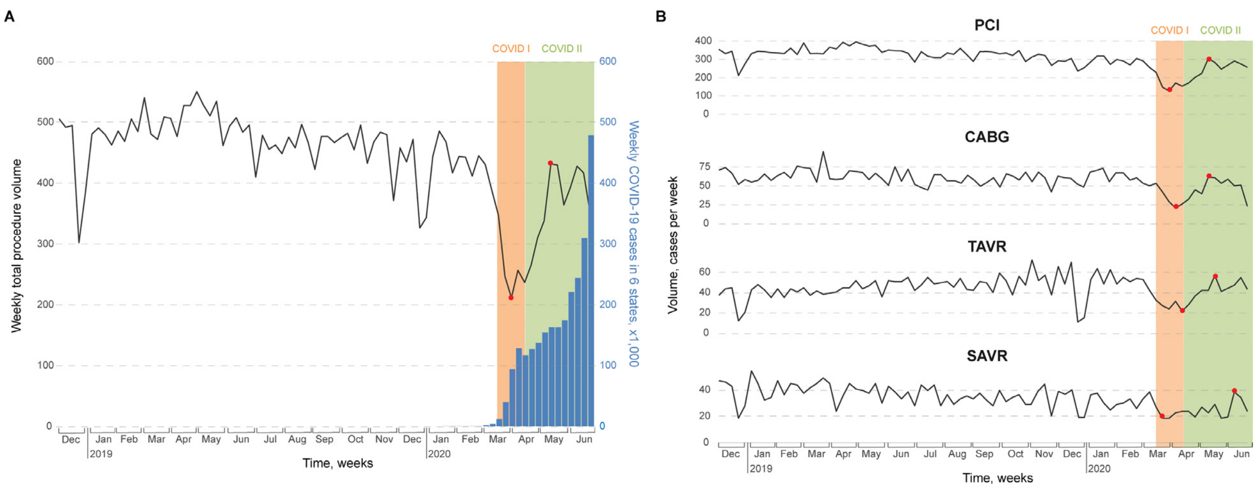
[†] Isolated CABG

[‡] TAVR / TAVR combos

[§] SAVR / SAVR with CABG or PCI

[||] Long-distance travel was defined as distance between patient and hospital zip code greater than the third quartile (31 miles) of the distance distribution.

Figure 1



Cardiovascular procedural volumes during the COVID-19 pandemic. A, procedural volumes and concomitant COVID-19 burden over time. Black line represents procedural volumes over time. Blue bars represent COVID-19 burden in the counties studied over time. Red dots represent the nadir and peak of procedural volumes during COVID I and II. Orange shading represents the COVID I time period and green shading represents the COVID II time period. B, Procedure-specific volumes over time. Total weekly volumes for each procedure type are displayed as solid black lines. Red dots represent the nadir and peak of procedural volumes during COVID I and II. The COVID I time period (defined as the 2 weeks before and after the nadir, March 15 – April 11, 2020) is shaded dark orange and COVID II time period (defined as the post-COVID I period of recovery, April 12 – June 28, 2020) is shaded green (Color version of the figure is available online).

significant to account for Bonferroni adjustment for multiple comparisons. SAS (7.1) and R statistical programs were used for all analyses.

Results

From December 2, 2018 to June 28, 2020, we identified 36,152 unique cardiovascular procedures (69% PCI, 13% CABG surgery, 10% TAVR and 8% SAVR) at 30 hospitals across 6 states. These procedures involved 33,058 unique patients, of whom 8% had more than 1 procedure during the 20-month timeframe.

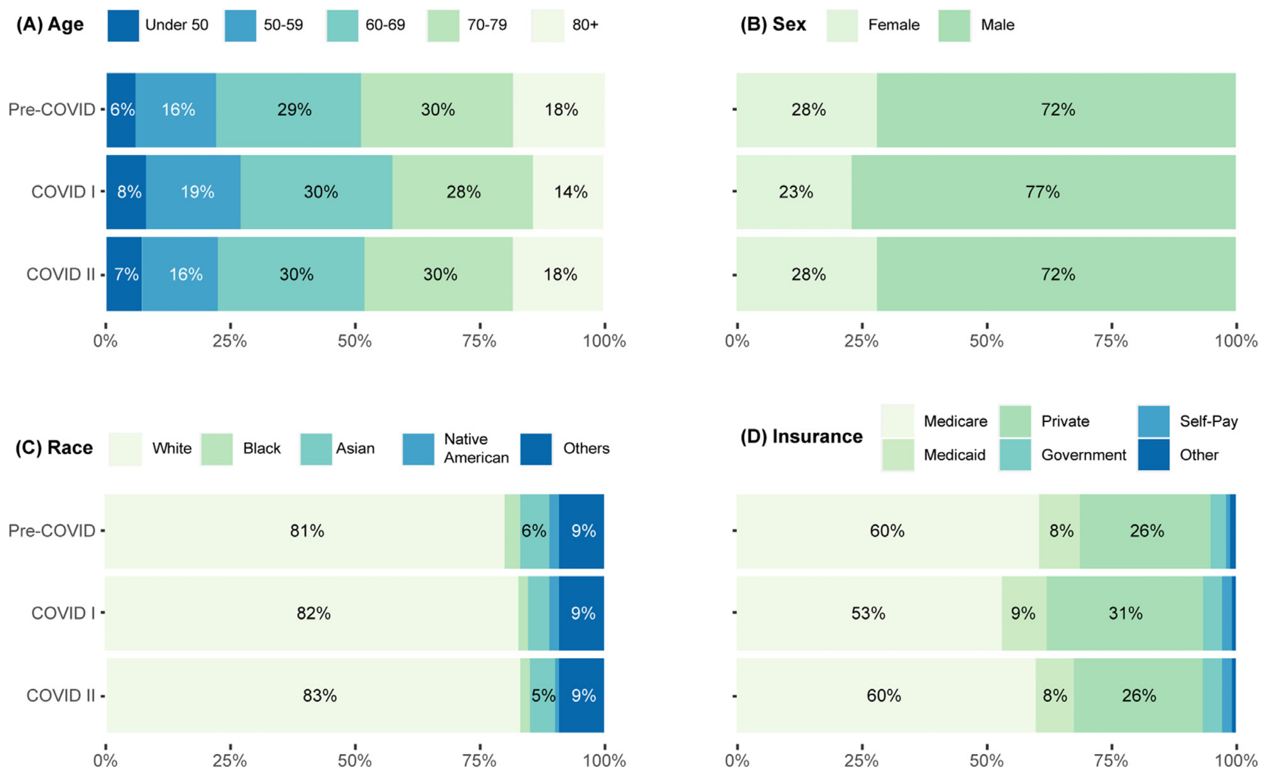
Procedural volumes over time

For all procedures combined, weekly volumes reached a nadir on March 29, 2020 (Figure 1A). Following the initial inflection on February 23, 2020, procedures decreased at a rate of -21 cases per week, from a pre-COVID weekly volume of 465 (95% CI 452, 478) down to a nadir weekly volume of 210, corresponding to a mean weekly volume during COVID I of 264 (95% CI 143, 385) and a 43% reduction from the pre-COVID period (Supplemental Table III). After the second inflection point (March 29, 2020), procedures increased at a rate of +15 cases per week to a peak weekly volume of 431 (May 10, 2020), corresponding to a mean weekly volume during COVID II of 359 (95% CI 305, 414, $P < .0001$) and a 23% reduction from the pre-COVID period. Analysis by each procedure type revealed that PCI, CABG surgery, and TAVR had largely consistent volumes leading up to the pandemic (Figure 1B). A brief drop in aortic valve procedures was noted during the 2018 and 2019 winter holiday periods along with a gradual decline in overall SAVR volumes over the entire pre-COVID period. Analysis of statistical inflection points unique to each procedure revealed that PCI and TAVR volumes started to decline as early as the week of February 16, 2020. Whereas CABG surgery volumes started to decline slightly later on March 1, 2020, no significant inflection points were found for SAVR. For PCI, CABG surgery, and TAVR, the appreciable decrease in procedural volume found during COVID I was followed by active recovery of cases during COVID II.

Patient demographics by COVID phase

Patient demographics varied significantly by COVID phase (Table I, Figure 2). Compared to pre-COVID, patients in COVID I ($n = 1056$) were less likely to be older (median 67 [IQR 59-76] vs pre-COVID 69 [IQR 61-77], $P < .0001$), female (23% vs pre-COVID 28%, $P = .0003$) and Black or Asian (2.0% and 3.9% respectively vs pre-COVID 2.5% and 5.6% respectively, $P = .02$ for all races). The proportion with Medicare insurance also dropped from 60% pre-COVID to 53% during COVID I, before returning to 60% in COVID II. In contrast, there was an increase in the proportion of patients in COVID I who had low income/Medicaid, government, or private insurance (9.3%, 4.5%, 31% respectively vs pre-COVID 8.2%, 2.8%,

Figure 2



Demographic changes in procedural deferral by COVID-19 phase. Significant demographic changes between COVID time periods for age A, ($P < .0001$), sex B, ($P = .0003$), race C, ($P = .019$), and insurance type D, ($P < .0001$). Numbers <5% were omitted from the figure for clarity.

26% respectively, $P < .0001$ across all insurance types). Baseline comorbidities did not change significantly over the study period, except for heart failure, which increased in prevalence from pre-COVID to COVID I, followed by a slight decrease in COVID II (35% to 38% to 37% respectively, $P = .001$).

Sub-group analysis of patient demographic changes between time periods for each of the 4 procedural categories showed similar trends as above (Supplemental Table IV). After Bonferroni adjustment for multiple comparisons, the only additional significant finding was a decrease in the proportion undergoing PCI as an outpatient from pre-COVID to COVID-I, with a return to baseline during COVID II (35% to 29% to 35% respectively, $P = .002$).

Relationship of procedural deferral to local COVID-19 case burden

During COVID I, there was no significant correlation between local COVID-19 case burden and changes in procedural volume (correlation coefficient -0.27, $P = .16$ for COVID I). During COVID II, however, there was a trend toward decreased procedural volumes in areas with higher COVID-19 case rates (correlation coefficient -0.36, P-value $= .054$ for COVID II, Figure 3, Supplemental Table V).

Acuity of indication by COVID phase

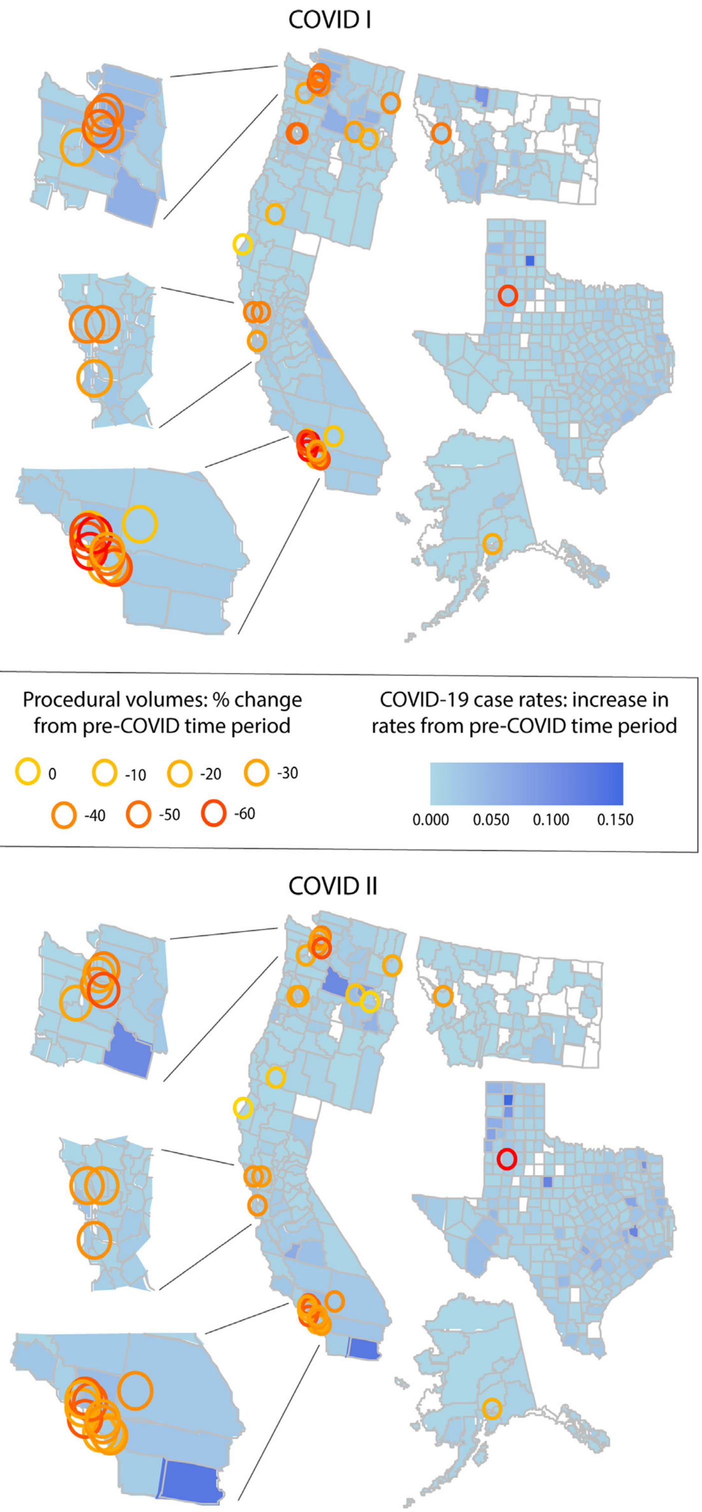
For those undergoing PCI, the acuity of indication changed by COVID phase ($P < .0001$ across all indications, Figure 4). Compared to pre-COVID, the proportion with STEMI during COVID I increased from 21% to 28%, before decreasing down to 23% during COVID

II. The proportion presenting with NSTE-ACS increased by a small amount from pre-COVID to COVID I (39%-42%), with a decrease in those presenting with SIHD during the same time frame (19% to 14%).

Procedural complexity by COVID phase

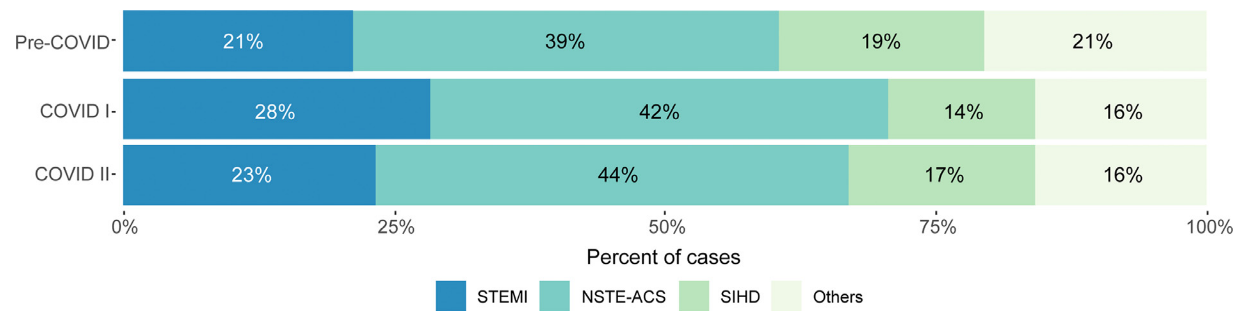
For aortic stenosis procedures, non-significant trends in procedural complexity across COVID phases were observed ($P = .18$ for TAVR and $P = .9$ for SAVR, Figure 5). Compared to pre-COVID, patients undergoing TAVR during COVID I were more likely to be coded as having

Figure 3



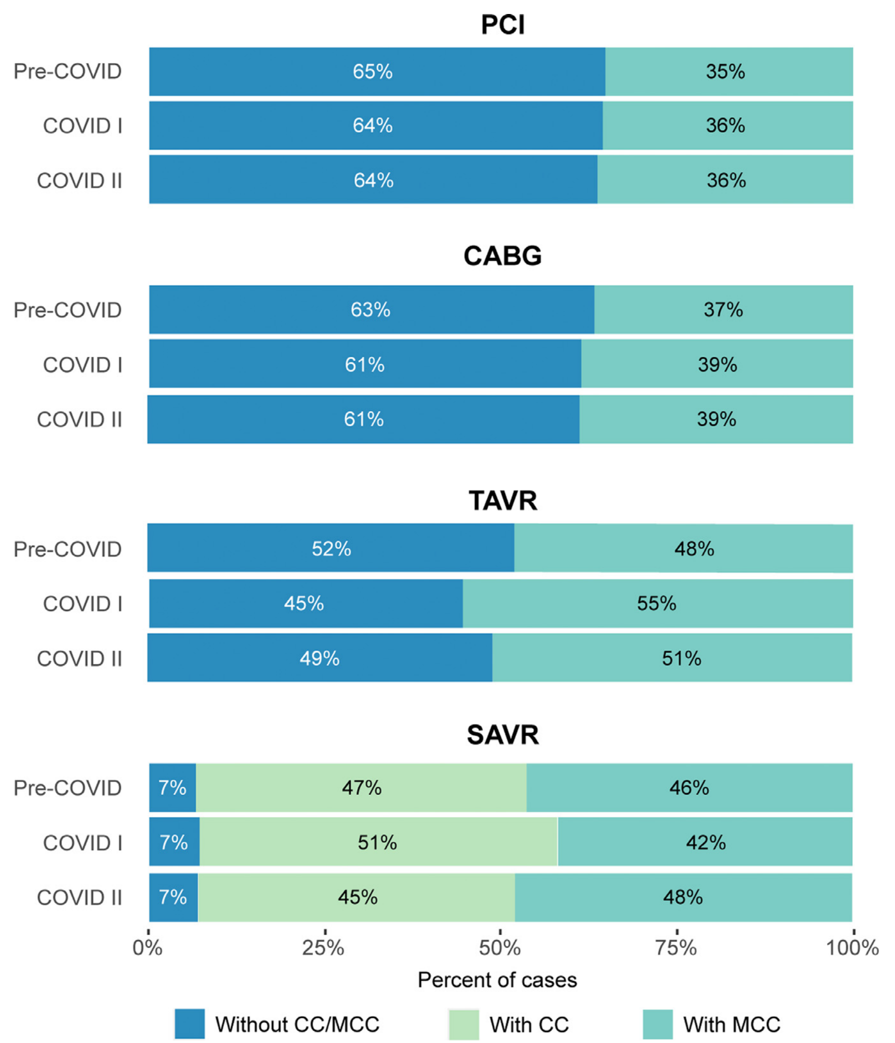
Magnitude of procedural deferral by facility mapped to COVID-19 burden by county for COVID I and COVID II. COVID-19 burden normalized to county population, with both periods compared to pre-COVID phase. Correlation coefficients: COVID I = - 0.27, P = .20, COVID II = -0.36, P = .054.

Figure 4



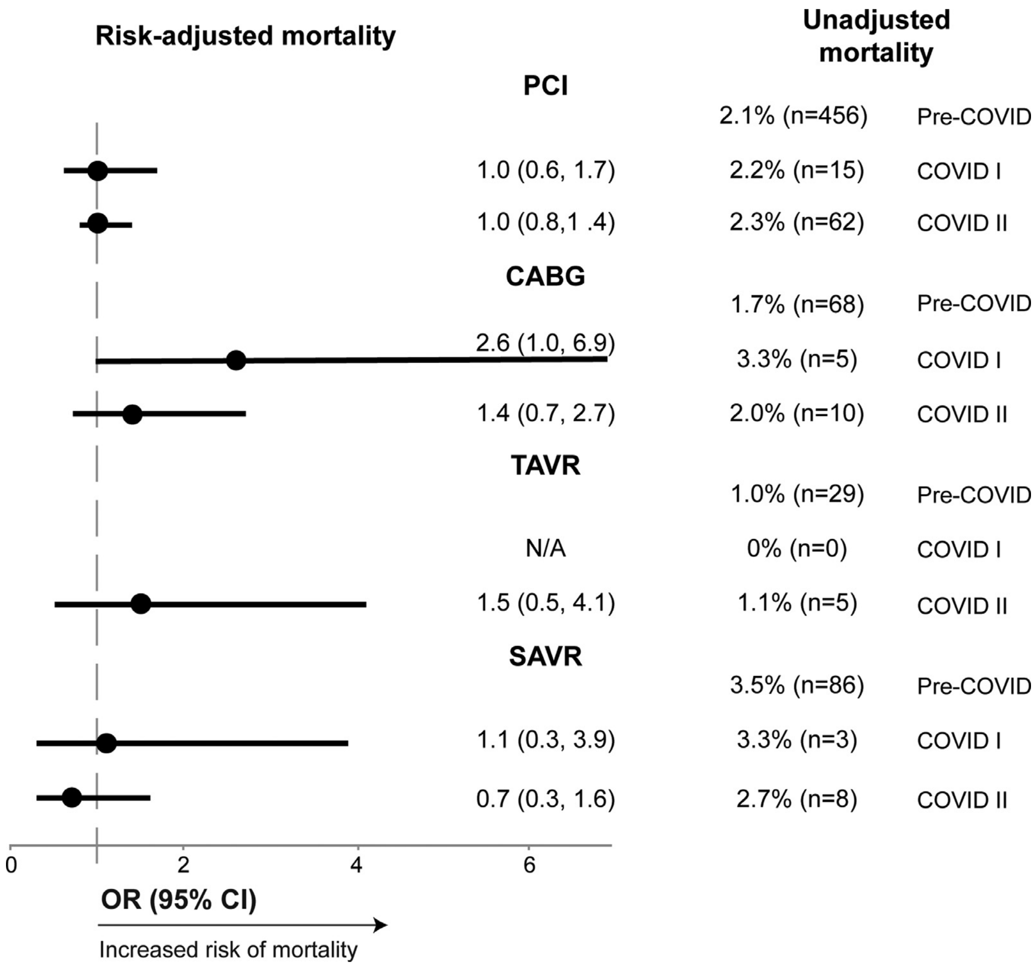
Indication for revascularization with PCI by COVID-19 phase. Changes in indication between time periods were statistically significant ($P <$ .0001).

Figure 5



Procedural complexity by COVID-19 phase. DRG categories for inpatient cases.

Figure 6



Adjusted and unadjusted in-hospital mortality by procedure type and COVID-19 phase. All demographics and comorbidities from Table I were included in the risk-adjusted mortality models.

"with MCC" for their MS-DRG (48%-55%). In contrast, patients undergoing SAVR saw a decrease in this over the same time frame (46%-42%). No trends in procedural complexity were found for patients undergoing coronary revascularization.

Outcomes by COVID phase

Compared to pre-COVID, there were no significant differences in in-hospital mortality during COVID I or II for any of the 4 procedures, both before, and after risk adjustment (Figure 6). There was, however, a strong trend toward a higher mortality rate after CABG surgery in COVID I compared to pre-COVID (adjusted OR 2.61 [95% CI 0.98, 6.93]). Based on this, and as part of a sensitivity analysis, we analyzed mortality using the statistically-derived inflection point dates (redefining COVID I as the 4-week period starting on the first inflection point date), and found a statistically higher mortality rate after CABG surgery during COVID I, both before and after risk adjustment (OR 2.50 [95% CI 1.26, 4.92] and OR 2.86 [95% CI 1.38, 5.93], respectively). No differences were observed for the other procedures. To account for within hospital correlation of patient outcomes, we also took hospital as a random effect, and found no change in overall mortality (compared to pre-COVID: COVID I OR 1.06 [95% CI 0.68, 1.65], COVID II OR 1.01 [95% CI 0.79, 1.30]. There were also no changes in procedure specific mortality (Supplemental Table VI).

For all procedures combined, there was no change in LOS from pre-COVID to COVID I (median 3.2 [IQR 1.8-6.8] days to 3.2 [IQR 1.6-6.2] days); a small decrease was observed in COVID II (median 3.0 [IQR 1.8- 6.3] days, $P = .001$). For those that underwent CABG surgery, LOS decreased from pre-COVID to COVID I (median 7.3 [IQR

5.4-10] days to 6.9 [IQR 4.8-9.9] days), with a near return to baseline in COVID II (median 7.2 [IQR 5.3-10] days, $P = .01$). There were no significant changes in LOS among the other procedure types.

Discussion

We report findings from a large, multi-center study that evaluated cardiovascular procedural volumes and outcomes during early periods of the COVID-19 pandemic among diverse patient populations in the United States. Important observations include a significant decline in procedural volume that began on February 23, 2020, reaching a nadir on March 29, 2020; this was followed by a partial recovery. It is noteworthy that by using statistical analysis to define the inflection point, procedural deferrals were noted to predate national mandates. Second, we observed changes in patient demographics for those treated during COVID I, including differences by age, sex, race, and insurance type. Third, despite increased acuity of procedural indication during COVID I, no significant changes in risk-adjusted in-hospital mortality were observed.

While the first case of COVID-19 in the United States was identified in February 2020, it was not until mid-March of 2020 that the American College of Cardiology and Society of Angiography and Intervention published a consensus statement regarding deferral of cardiovascular procedures, occurring in tandem with release of federal mandates and shelter-in-place orders[2–4]. Our data suggest that procedural volumes actually began to decline before formal implementation of these policies, by as much as 1 month. While a prior study from England noted a decline in procedural volumes from March through May 2020, continuous volume curves were not evaluated.[8] It is unclear the degree to which early deferrals in our study were driven by declining patient demand versus a curtailed supply by physicians, though prior studies demonstrating significant drops in presentations for acute conditions during the pandemic suggest that patients may have started to avoid hospital-based procedures even before physicians and policymakers were formally deferring them.[5,9–11]

Interestingly, SAVR volumes in our study appeared to be the exception, with a gradual decline in volume over time that was unaltered by the COVID-19 pandemic. With the rise in TAVR volumes over the last decade partially supplanting a portion of SAVR procedures,[12,13] it is speculative that the patients referred for SAVR may have had specific treatment indications that required timely intervention, impervious to outside forces. A small study of aortic stenosis patients receiving treatment in Switzerland during the pandemic showed that none of their patients received SAVR during the March-April, 2020 period, and all were directed to either expedited or deferred TAVR.[14] In the setting of severe resource constraints, it is possible that aortic stenosis patients who might normally be offered both treatment options might be steered toward the less invasive one, in hopes of minimizing time in the hospital.

Investigation into the changing demographics of patients who were treated during different phases of COVID-19 suggest either prioritization or self-selection of certain patient populations for procedural treatment during the COVID I period. The finding that COVID I patients were both younger and less likely to have Medicare insurance is consistent with suspected reluctance by older patients to seek care given early data suggesting a higher COVID-19 mortality in this population.[15] Beyond this, however, we also found a decrease in the proportion of Blacks and Asians treated during the COVID I period. Among potential drivers, we know that resource constraints during the pandemic resulted in longer door-to-balloon times, with discussion about treating COVID-19 STEMI patients with a fibrinolytic-first rather than primary PCI strategy.[16,17] With a higher burden of COVID-19 among racial/ethnic minorities,[18] changes in treatment strategies might have also impacted this group more. Social, financial, and environmental strains from the pandemic, as well as misinformation, may also have disproportionately impacted vulnerable populations, resulting in greater barriers to seeking timely care.

Based on our analysis of the relationship between procedural deferral and local COVID-19 burden, we discovered a slight trend toward an association between the 2 during COVID II, but not COVID I. This suggests that deferral during COVID I may have followed mandates irrespective of local COVID-19 burden, but that once this acute period was over, hospitals may have started to variably resume care based on severity of local COVID-19 conditions. Interestingly, findings during the COVID I period in New York City did show that high density COVID-19 counties experienced more procedural deferral than low density counties.[19] Combined with our data, this suggests that perhaps a certain threshold is necessary before local COVID-19 burden directly impacts procedural deferrals (which were not reached on the West Coast during COVID I). Further studies to distinguish the degree to which deferral was driven by patients, clinicians, or facilities will be vital to inform plans in a post-COVID-19 era and in the event of future major healthcare disruptions. If patient fears are the primary driver of the reduction in procedures, as some early data has suggested,[20–23] then strong patient and public education efforts will be critical to ensuring that patients overcome concerns about coming to the hospital for treatment of their cardiovascular disease.

Notable changes in procedural volume by COVID-19 phase raise the question of what kinds of indications and procedure types were prioritized during these periods. The fact that STEMI comprised a larger proportion of indications for PCI during COVID I is consistent with stated national goals of performing only urgent, life-saving procedures at that time. Importantly, with resumption of procedures in COVID II, we sought to answer the question of whether the first patients to be prioritized would be a second tier of very sick patients who had their procedure deferred during COVID I,[24] or whether they would mirror the pre-COVID population. Our findings suggest that the patients who received procedures in COVID II had less acute indications compared to those in COVID I, but still slightly greater acuity than that noted in the pre-COVID period. The trends of increased procedural complexity for TAVR with simultaneous decreased complexity for SAVR during COVID I also raise the possibility that some aortic stenosis patients who might have normally been treated with SAVR were directed to a less invasive alternative due to pandemic constraints, at the expense of increased procedural complexity.

It is reassuring that despite increasing acuity and complexity of procedures during COVID I, we found no significant differences in risk-adjusted in-hospital mortality. The fact that patient outcomes remained unchanged during the worst phases of the pandemic goes a long way to helping patients rebuild the confidence to resume care as the pandemic continues. Our data support findings from a meta-analysis that showed no difference in mortality after STEMI despite increased door-to-balloon times during the pandemic.[25] However, our sensitivity analysis of mortality (based on statistically-derived inflection point dates) did show a higher risk-adjusted mortality rate after CABG surgery, raising concern that subtle changes in outcomes may have actually occurred depending on the exact dates studied. One possible explanation is that even before formal policy changes were implemented in mid-March 2020, low-risk surgical candidates may have already anticipated the COVID-19 surge and decided to defer their own treatment early, leaving only higher-risk, higher-complexity patients to be treated. This may not have been mirrored among percutaneous procedural candidates due to the minimally invasive nature of those procedures. In theory, risk adjustment should have accounted for these differences, but we recognize that the pandemic may have also changed the way that healthcare was delivered. For example, 1 possibility is that the quality of treatment during this period may have suffered, with many staff reassigned to other COVID-19-related duties. It is promising that despite the known significant risks of deferring treatment for severe aortic stenosis,[26,27] our data suggests that patients and clinicians were able to prioritize those most in need of a procedure without a change in short-term mortality. Only time will tell, however, whether there are long-term impacts from these delays.

Whereas the unchanged length of stay during COVID I may be representative of efforts to minimize time in the hospital, the decreased length of stay during COVID II is likely reflective of patients with lower acuity and complexity. These findings differ slightly from a single center study showing shorter lengths of stay for all cardiovascular admissions, but these were not uniquely focused on those related to procedures.[5] Our findings of a lower proportion of outpatient procedures performed in COVID I confirm that patients being treated during this time were predominantly non–elective cases.

This study has several limitations. While our dataset is largely limited to the Western United States, the diversity within our sample suggests high likelihood of applicability to other states, albeit with differences in phase dating. Even though we adjusted for multiple patient characteristics and comorbidities, additional (and potentially unrecognized) confounders may still exist. For example, we adjusted for long-distance travel, but we recognize that the significance of distance in miles may differ in rural and urban areas. In addition, while we assigned one primary procedure as the culprit for mortality based on clinical likelihood, it is possible that other scenarios may have taken place. Importantly, our use of ICD-10 and MS-DRG codes is subject to coding-related limitations and we were unable to collect certain clinical and procedural details, including echocardiographic data. We also assumed that patients did not switch out of hospitals or healthcare systems during the study period. Finally, we did not capture out of hospital deaths or mortality over a longer time horizon.

Conclusion

The COVID-19 pandemic has produced an unprecedented natural experiment, allowing assessment of broad procedural deferral at scale. While the full impact may not be realized for years, our evaluation helps to inform ongoing responses to the pandemic, as well as future strategies to address workforce disruptions and abrupt changes in operational capacity or funding. Importantly, our findings related to vulnerable populations also serve as a harbinger of widening health disparities beyond COVID-19, reinforcing the importance of thoughtful strategies to minimize the indirect toll of the pandemic.

Author CRediT roles

Celina Yong: Conceptualization, Formal Analysis, Methodology, Project administration, Supervision, Writing-original draft and review/editing; Kateri Spinelli: Conceptualization, Formal Analysis, Methodology, Project administration, Writing-original draft and review/editing; Shih Ting Chiu: Methodology, Formal Analysis; Brandon Jones: Conceptualization, Formal analysis, Methodology, Writing- review/editing; Brian Penny: Data collection; Santosh Gummidipundi: Data collection; Shire Beach: Data collection, Writing- review/editing; Alex Perino: Conceptualization, Writing-review/editing; Mintu Turakhia: Conceptualization, Writing- review/editing; Paul Heidenreich: Conceptualization, Writing- review/editing; Ty Gluckman: Conceptualization, Formal Analysis, Methodology, Supervision, Writing-original draft, and review/editing.

Funding

CMY is funded by a Career Development Award from the United States (U.S.) Department of Veterans Affairs Health Services Research & Development Service of the VA Office of Research and Development.

Disclosures

MT: Grants - Janssen Inc, Boehringer Ingelheim, Cardiva Medical, Bristol-Meyers Squibb, American Heart Association, Sentre Heart, Apple, Bayer; Consulting - Medtronic Inc, Abbott, Cardiva Medical, iRhythm, Novartis, Biotronik, Sanofi, Pfizer, Myokardia, Johnson & Johnson, Milestone Pharmaceuticals; Other - editor for JAMA Cardiology. AP: Grants – American Heart Association, Bristol-Meyers Squibb/Pfizer; Consulting – Bristol-Myers Squibb/Pfizer. CMY, KJS, STC, BJ, BP, SG, SB, PH, TJG: None.

Acknowledgments

Special thanks to Alison Leiataua, MSc for assistance with tables and figures.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ahj.2021.06.011.

References

1. Schuchat A. Public health response to the initiation and spread of pandemic COVID-19 in the United States, February 24–April 21, 2020. MMWR Morb Mortal Wkly Rep 2020;69. doi:10.15585/mmwr.mm6918e2.
2. Welt FGP, Shah PB, Aronow HD, et al. American College of Cardiology's Interventional Council and the Society for Cardiovascular Angiography and Interventions. Catheterization laboratory considerations during the coronavirus (COVID-19) pandemic: from the ACC's Interventional Council and SCAI. J Am Coll Cardiol 2020;75:2372–5.
3. COVID-19 response plan. Veterans Health Administration - Office of Emergency Management; 2020. Available at https://www.va.gov/opa/docs/VHA_COVID_19_03232020_vF_1.pdf. Accessed at: April 30, 2020.
4. Coping with stress. COVID-19. Centers for Disease Control and Prevention. Available at https://www.cdc.gov/coronavirus/2019-ncov/daily-life-coping/managing-stress-anxiety.html. Accessed at: April 30, 2020.
5. Bhatt AS, Moscone A, McElrath EE, et al. Fewer hospitalizations for acute cardiovascular conditions during the COVID-19 pandemic. J Am Coll Cardiol 2020;76:280–8.
6. Calculate distance and bearing between two Latitude/Longitude points using haversine formula in JavaScript. Available at http://www.movable-type.co.uk/scripts/latlong.html. Accessed at: January 6, 2021.
7. nytimes/covid-19-data. The New York Times; 2021. Available at https://github.com/nytimes/covid-19-data. Accessed at: January 6, 2021.
8. MO Mohamed, Banerjee A, Clarke S, et al. Impact of COVID-19 on cardiac procedure activity in England and associated 30-day mortality. Eur Heart J Qual Care Clin Outcomes 2020. doi:10.1093/ehjqcco/qcaa079.
9. Gluckman TJ, Wilson MA, Chiu S-T, et al. Case rates, treatment approaches, and outcomes in acute myocardial infarction during the coronavirus disease 2019 pandemic. JAMA Cardiol 2020;5:1–6. doi:10.1001/jamacardio.2020.3629.
10. Solomon MD, McNulty EJ, Rana JS, et al. The covid-19 pandemic and the incidence of acute myocardial infarction. N Engl J Med 2020;383:691–3.
11. El-Hamamsy I, Brinster DR, DeRose JJ, et al. The COVID-19 pandemic and acute aortic dissections in New York. J Am Coll Cardiol 2020;76:227–9.
12 Hannan EL, Samadashvili Z, Stamato NJ, et al. Utilization and 1-year mortality for transcatheter aortic valve replacement and surgical aortic valve replacement in New York patients with aortic stenosis: 2011 to 2012. JACC Cardiovasc Interv 2016;9:578–85.
13. Mori M, Bin Mahmood SU, Geirsson A, et al. Trends in volume and risk profiles of patients undergoing isolated surgical and transcatheter aortic valve replacement. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv 2019;93:E337–42.
14. Ro R, Khera S, Tang GHL, et al. Characteristics and Outcomes of patients deferred for transcatheter aortic valve replacement because of COVID-19. JAMA Netw Open 2020;3.
15 CDC Morbidity and Mortality Weekly Report. Severe outcomes among patients with coronavirus disease 2019 (COVID-19) — United States, February 12–March 16, 2020. MMWR Morb Mortal Wkly Rep 2020;69. doi:10.15585/mmwr.mm6912e2.
16. Garcia S, Stanberry L, Schmidt C, et al. Impact of COVID-19 pandemic on STEMI care: an expanded analysis from the United States. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv 2020. doi:10.1002/ccd.29154.
17. Kwok CS, Gale CP, Kinnaird T, et al. Impact of COVID-19 on percutaneous coronary intervention for ST-elevation myocardial infarction. Heart 2020;106:1805–11.
18. Muñoz-Price LS, Nattinger AB, Rivera F, et al. Racial disparities in incidence and outcomes among patients with COVID-19. JAMA Netw Open 2020;3.
19. Hannan EL, Wu Y, Cozzens K, et al. Percutaneous coronary intervention for ST-elevation myocardial infarction before and during COVID in New York. Am J Cardiol 2020;142:25–34. doi:10.1016/j.amjcard.2020.11.033.
20. Garcia S, Albaghdadi MS, Meraj PM, et al. Reduction in ST-segment elevation cardiac catheterization laboratory activations in the United States during COVID-19 pandemic. J Am Coll Cardiol 2020;75:2871–2. doi:10.1016/j.jacc.2020.04.011.
21. Lai PH, Lancet EA, Weiden MD, et al. Characteristics associated with out-of-hospital cardiac arrests and resuscitations during the novel coronavirus disease 2019 pandemic in New York City. JAMA Cardiol 2020;5:1154–63. doi:10.1001/jamacardio.2020.2488.

22. De Rosa S, Spaccarotella C, Basso C, et alSocietà Italiana di Cardiologia and the CCU Academy investigators group. Reduction of hospitalizations for myocardial infarction in Italy in the COVID-19 era. Eur Heart J 2020;41:2083–8.
23 Yong CM, Ang L, Welt FGP, et al. Society for Cardiovascular Angiography and Interventions (SCAI) and the American College of Cardiology (ACC) Interventional Council. Cardiac procedural deferral during the coronavirus (COVID-19) pandemic. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv 2020;96:1080–6.
24. Ryffel C, Lanz J, Corpataux N, et al. Mortality, stroke, and hospitalization associated with deferred vs expedited aortic valve replacement in patients referred for symptomatic severe aortic stenosis during the COVID-19 pandemic. JAMA Netw Open 2020;3.
25. Rattka M, Dreyhaupt J, Winsauer C, et al. Effect of the COVID-19 pandemic on mortality of patients with STEMI: a systematic review and meta-analysis. Heart 2020. doi:10.1136/heartjnl-2020-318360.
26. Malaisrie SC, McDonald E, Kruse J, et al. Mortality while waiting for aortic valve replacement. Ann Thorac Surg 2014;98:1564–71.
27. Elbaz-Greener G, Masih S, Fang J, et al. Temporal trends and clinical consequences of wait times for transcatheter aortic valve replacement: a population-based study. Circulation 2018;138:483–93.