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National Trends of Structural Heart Disease Interventions from 2016 to 2020 in the United States and the Associated Impact of COVID-19 Pandemic

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Abstract: The Coronavirus Disease-2019 (COVID-19) pandemic placed an enormous strain on the healthcare system. Data on the impact of COVID-19 on the utilization and outcomes of structural heart disease interventions in the United States are scarce. The National Inpatient Sample from 2016 to 2020 was queried to identify adult admissions for transcatheter aortic valve replacement (TAVR), left atrial appendage occlusion (LAAO), and transcatheter end-to-end repair (TEER). The primary outcome was temporal trends of procedure utilization rate per 100,000 admissions over...
quarters from 2016 to 2020. The secondary outcomes were adjusted rates of in-hospital mortality, major complications, and length of stay (LOS).

Among 434,630 weighted admissions (TAVR: 305,550; LAAO: 89,300; TEER: 40,160), 95,010 admissions (22%) were during the COVID-19 era. There was a decline during the second quarter of 2020 followed by an increase to the pre pandemic levels (TAVR: 220 to 253, LAAO: 57 to 109, and TEER: 31 to 36 per 100,000 admissions, Ptrend < 0.001). There were no differences in the mortality or major complication rates. Median LOS has decreased in TAVR (4 days-1 day) and in TEER (3 days-1 day) but remained stable in LAAO (1 day). This nationwide analysis showed that structural heart disease interventions decreased during the early waves of COVID-19 pandemic. There was a significant reduction in hospital LOS without differences in in-hospital mortality or complication rates during the pandemic. These data suggest that hospitals adapted to the unprecedent challenges during the pandemic to provide advanced cardiac care to patients. (Curr Probl Cardiol 2023;48:101526.)

Introduction

The Coronavirus Disease-2019 (COVID-19) pandemic has had profound implications on the management of cardiovascular diseases. In March 2020 when the World Health Organization (WHO) declared the COVID-19 pandemic, uncertainties regarding the spread of the disease and the enormous strain on the healthcare system led to elective procedures being curtailed or deferred at institutions nationwide. As our understanding of the SARS-CoV2 virus evolved, societal recommendations for performances of structural heart disease (SHD) interventions such as transcatheter aortic valve replacement (TAVR), left atrial appendage occlusion (LAAO), and transcatheter end-to-end repair (TEER) have been updated. Recognizing the mortality and morbidity associated with delaying SHD interventions, the American College of Cardiology and Society for Cardiovascular Angiography and Interventions released a combined statement providing guidance on triaging patients in need of these interventions. These recommendations
were intended to balance the risks of contracting COVID-19 against the benefits of reducing morbidity and mortality associated with postponement of SHD interventions.

To provide advanced cardiac care to patients during the pandemic, we speculate institutions adapted and successfully triaged patients for procedures. The decline of SHD procedure rates have been reported in several studies in the United States and globally.3-9 However, nationwide analysis of trends in SHD interventions particularly following the initial phase of the pandemic has not been reported. Our study highlights the national trends in SHD interventions and associated outcomes during that period.

**Methods**

**Data Source**

This is an observational cohort study using the Agency for Healthcare Research and Quality’s Healthcare Cost and Utilization Project National Inpatient Sample (NIS) from January 2016 to December 2020.10 The NIS is the largest publicly available all-payer inpatient care database that approximates a 20% stratified sample of discharges from the United States (US) hospitals. Each admission is weighted to make the NIS nationally representative. Unweighted, the NIS contains data on approximately 7 million admissions each year. Weighted, it estimates roughly 35 million discharges. The NIS contains both patient and hospital-level information. Up to 40 discharge diagnoses and 25 procedures are collected for each patient using the International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM), and International Classification of Diseases, Tenth Revision, Procedure Coding System (ICD-10-PCS), respectively. National estimates were produced using sampling weights provided by the sponsor. All values presented are weighted estimates.

**Study Population**

All adult admissions with TAVR, LAAO, and TEER from 2016 to 2020 were included in the study. Procedures were identified using ICD-10-PCS codes (TAVR: 02RF3JZ, 02RF3KZ, 02RF38Z, 02RF37Z, 02RF47Z, 02RF48Z, 02RF4JZ, 02RF4KZ, X2RF332, X2RF432, 02RF37H, 02RF38H, 02RF3JH, 02RF3KH; LAAO: 02L73DK; TEER: 02UG3JZ).
In accordance with the Healthcare Cost and Utilization Project data use agreement, we omitted reporting any variable containing a small number of observations (<11) that could pose risk of person identification or data privacy violation.

**Study Outcomes**

The primary outcome was the temporal trends of each procedure utilization rate per 100,000 admissions over quarters from 2016 to 2020. The secondary outcomes were adjusted in-hospital mortality, major complications (ie, acute ischemic stroke (AIS) and post-procedural hemorrhage as well as in-hospital pacemaker placement in TAVR), and length of stay (LOS) before versus during the COVID-19 era. The COVID-19 era was identified as admissions from March 2020 to December 2020. In-hospital mortality and LOS are readily available in the NIS. Other complications were captured using ICD-10-CM codes (Supplemental Table 1).

**Statistical Analysis**

Data are presented as frequencies with percentages for categorical variables. Mean, standard deviation, median and interquartile range are reported for continuous variables as appropriate. Categorical variables were compared using Chi-Squared ($\chi^2$) tests and continuous variables were compared using Student’s t-test or Wilcoxon Rank Sum test as appropriate. A linear regression and Cochrane-Armitage tests were utilized to calculate the unadjusted temporal trends of procedures utilization per 100,000 admissions. Median LOS of procedures in each quarter was compared using Kruskal-Wallis equality-of-population rank test. Multivariate logistic (for binary variables) and linear (for linear variables) regression models adjusting for age, sex, and Charlson Comorbidity Index (CCI) score were used to study the impact of COVID-19 time on secondary outcomes. In these models, COVID-19 time was an independent binary variable. Hospital procedural volume were added to the model evaluating LOS. Hospitals were stratified according to procedure volume for each procedure into low (1st quartile), medium (2nd and 3rd quartiles) and high (4th quartile). Effect sizes were expressed using adjusted odds ratios (aOR) and 95% confidence intervals (CI) for categorical variables and adjusted Beta coefficient ($\alpha\beta$) for continuous variables. Sampling weights and clustering was accounted using “svyset” command. A secondary analysis using linear regression to calculate the adjusted trends of LOS for each procedure. Adjusted estimates were
presented as predictive margins, which are standardized to the covariate distribution of the study population. All P values were 2-sided with a P value of 0.05 as the threshold for statistical significance. The study was exempted from Institutional Board Review (IRB) due to the de-identified nature of the database. Analysis was completed using STATA 17 STATA Corp College Station, TX.

Results

Baseline Characteristics

A total of 434,630 admissions (TAVR: 305,550; LAAO: 89,300; TEER: 40,160) were included in the analysis, of which 95,010 admissions (22%) were during the COVID-19 era (Fig 1). Baseline characteristics of each procedure are stratified according to the time of procedure (pre and during COVID-19) (Table 1-3).

For TAVR, admissions during COVID-19 were more likely to be younger, had lower mean CCI score, and less comorbidity burden (heart failure 71% vs 74%, atrial fibrillation 35% vs 38%, prior CABG 12% vs 16% and chronic kidney disease 31% vs 35%) (Table 1).

For LAAO, although comorbidity burden was generally comparable between admissions pre-COVID-19 and during COVID-19, heart failure was more prevalent during COVID-19. Mean CCI was higher in admissions during COVID-19 (Table 2).

For TEER, admissions during COVID time were more likely to have a higher mean CCI, and higher comorbidity burden (heart failure, hypertension, diabetes mellitus and chronic kidney disease) (Table 3).

Primary Outcome

The number of TAVR procedures increased from 96 to 253 per 100,000 admissions from quarter 1 (Q1) of 2016 to quarter 4 (Q4) of 2020 ($P_{trend}$ <0.001). However, there was a decline in procedural rates in quarter 2 (Q2) of 2020, down to 220 per 100,000 admissions.

Similarly, from Q1 2016 to Q4 2020, procedure rate increased from 10 to 109 per 100,000 admissions ($P_{trend}$<0.001), and 12 to 36 per 100,000 admissions ($P_{trend}$ <0.001) in LAAO and TEER, respectively. Similar to TAVR, lower rates of LAAO and TEER were observed in Q2 of 2020 (57/100,000 admissions in LAAO and 31/100,000 admissions in TEER) (Fig 2) (Table 4).
FIG 1. Flow diagram of the study sample. (Color version of figure is available online.)

Combined TAVR/LAAO = 210
Combined TAVR/TEER = 150
Combined LAAO/TEER = 20

NIS: National Inpatient Sample; SHD: Structural Heart Disease; TAVR: Transcatheter Aortic Valve Replacement; LAAO: Left Atrial Appendage Occlusion; TEER: Transcatheter End-to-End Repair
| Baseline characteristics | Prepandemic (n = 242,380) | During pandemic (n = 63,170) | P Value |
|--------------------------|---------------------------|-----------------------------|---------|
| Mean age in years (SD)   | 79.2 (7.8)                | 77.7 (7.8)                  | <0.001  |
| Female sex (%)           | 109,915 (45)              | 26,240 (42)                 | <0.001  |
| Hospital region          |                           |                             | 0.81    |
| Northeast (%)            | 56,220 (23)               | 13,355 (21)                 |         |
| Midwest (%)              | 54,935 (23)               | 14,935 (24)                 |         |
| South (%)                | 82,520 (34)               | 21,700 (34)                 |         |
| West (%)                 | 48,705 (20)               | 13,180 (21)                 |         |
| Primary Payor            |                           |                             | <0.001  |
| Medicare (%)             | 215,285 (89)              | 54,210 (86)                 |         |
| Medicaid (%)             | 3345 (1)                  | 905 (1)                     |         |
| Private (%)              | 18,160 (8)                | 6210 (10)                   |         |
| Self-Pay (%)             | 1075 (<1)                 | 315 (<1)                    |         |
| Other (%)                | 4235 (2)                  | 1480 (2)                    |         |
| Race                     |                           |                             | 0.56    |
| White (%)                | 204,165 (87)              | 54,095 (88)                 |         |
| Black (%)                | 9810 (4)                  | 2405 (4)                    |         |
| Hispanic (%)             | 11,340 (5)                | 2915 (5)                    |         |
| Asian/Pacific Islander (%)| 3145 (1)                 | 850 (1)                     |         |
| Native American (%)      | 690 (<1)                  | 190 (<1)                    |         |
| Other (%)                | 5505 (2)                  | 1160 (2)                    |         |
| Charlson comorbidity index (CCI) Score |             |                             | <0.001  |
| 0 (%)                    | 15,655 (6)                | 5185 (8)                    |         |
| 1 (%)                    | 44,750 (18)               | 13,175 (21)                 |         |
| 2 (%)                    | 48,995 (20)               | 12,780 (20)                 |         |
| 3 (%)                    | 43,855 (18)               | 10,955 (17)                 |         |
| ≥4 (%)                   | 89,125 (37)               | 21,075 (33)                 |         |
| Mean CCI (SD)            | 2.6 (1.2)                 | 2.5 (1.2)                   | <0.001  |
| Hypertension (%)         | 217,430 (90)              | 56,805 (90)                 | 0.59    |
| Diabetes Mellitus (%)    | 91,145 (38)               | 23,945 (38)                 | 0.58    |
| Heart failure (%)        | 178,795 (74)              | 44,850 (71)                 | 0.01    |
| Atrial fibrillation (%)  | 92,475 (38)               | 22,065 (35)                 | <0.001  |
| Chronic kidney disease (%)| 84,230 (35)              | 19,575 (31)                 | <0.001  |
| Dialysis (%)             | 5585 (2)                  | 1945 (3)                    | <0.001  |
| Anemia (%)               | 80,690 (33)               | 17,090 (27)                 | <0.001  |
| Liver disease (%)        | 8450 (3)                  | 2530 (4)                    | 0.01    |
| Cancer (%)               | 9305 (4)                  | 2560 (4)                    | 0.27    |
| Prior PCI (%)            | 53,195 (22)               | 13,140 (21)                 | 0.03    |
| Prior CABB (%)           | 39,720 (16)               | 7860 (12)                   | <0.001  |
| Prior valve replacement (%)| 7310 (3)                 | 1940 (3)                    | 0.80    |
| Unadjusted outcomes      |                           |                             |         |
| In-hospital mortality (%)| 3400 (1.4)                | 740 (1.2)                   | 0.06    |
| Acute ischemic stroke (%)| 3465 (1.4)                | 760 (1.2)                   | 0.049   |
| New pacemaker placement (%)| 18,650 (7.7)              | 3495 (5.5)                  | <0.001  |

(continued)
Secondary Outcomes

**TAVR.** On multivariate analysis, there was no difference in the rates of in-hospital mortality (1.4% vs 1.2%, aOR: 0.89 [0.73-1.08], \(P = 0.25\)), and AIS (1.4% vs 1.2%, aOR: 0.94 [0.78-1.12], \(P = 0.47\)). Admissions during COVID-19 were less likely to receive a new permanent pacemaker (5.5% vs 7.7%, aOR: 0.73 [0.66-0.80], \(P < 0.001\)), and less likely to have post-procedural hemorrhage (1.0% vs 1.5%, aOR: 0.68 [0.55-0.84], \(P < 0.001\)). Admissions during COVID-19 had lower mean length of stay (a\(\bar{b}\): -0.77 days, \(P < 0.001\)). Over the study period, mean LOS has decreased from 5.34 days, 95% CI (5.01-5.66) in Q1 2016 to 3.20 days, 95% CI (3.04-3.37) in Q4 2020 (Ptrend < 0.001) (Figure 3A). Median LOS decreased from 4 days (interquartile range [IQR]: 2-6 days) in Q1 2016 to 1 day (IQR: 1-3 days) in Q4 2020 (\(P < 0.001\)).

**LAAO.** As compared to pre COVID-19, admissions during COVID-19 were not associated with increased in-hospital mortality (0.1% vs 0.2%, aOR: 0.77[0.32-1.88], \(P = 0.57\)), AIS (0.4% vs 0.2%, aOR: 1.65 [0.87-3.13], \(P = 0.13\)), post-procedural hemorrhage (0.5% vs 0.5%, aOR:1.10 [0.68-1.78], \(P = 0.68\)) or length of stay (a\(\bar{b} = -0.07, P = 0.16\). Over the study period, mean LOS decreased from 1.75 days, 95% CI (1.31-2.19) in Q1 2016 to 1.37, 95% CI [1.25-1.48] in Q4 2020 (Ptrend < 0.001) (Figure 3B). Median LOS was stable in all quarters at 1 day (IQR 1-1 day) but hospitalizations with LOS > median were less in Q4 2020 than Q1 2016 (\(P < 0.001\)).

**TEER.** Similar to LAAO, complications rates were not different between during COVID-19 before COVID-19; in-hospital mortality (2.1% vs
### TABLE 2. Baseline characteristics and unadjusted outcomes of LAAO admissions stratified according to time of procedure (Pre and during COVID pandemic)

| Baseline characteristics | LAAO (n = 89,300) | P Value |
|--------------------------|-------------------|---------|
|                          | Prepandemic (n = 66,550) | During pandemic (n = 22,750) |   |
| Mean age in years (SD)   | 76.1 (7.3)         | 75.8 (7.2) | 0.04 |
| Female sex (%)           | 27,815 (42)        | 9430 (41)  | 0.67 |
| Hospital region          |                   |          | 0.93 |
| Northeast (%)            | 11,045 (17)        | 3565 (16) |       |
| Midwest (%)              | 14,810 (22)        | 5310 (23) |       |
| South (%)                | 26,195 (39)        | 9115 (40) |       |
| West (%)                 | 14,500 (22)        | 4760 (21) |       |
| Primary payor            |                   |          | 0.18 |
| Medicare (%)             | 59,080 (89)        | 19,945 (88) |       |
| Medicaid (%)             | 765 (1)            | 355 (2)   |       |
| Private (%)              | 5270 (8)           | 2060 (9)  |       |
| Self-Pay (%)             | 290 (<1)           | 70 (<1)   |       |
| Other (%)                | 1085 (1)           | 315 (1)   |       |
| Race                     |                   |          | 0.36 |
| White (%)                | 56,325 (87)        | 19,445 (89) |       |
| Black (%)                | 2750 (4)           | 985 (4)   |       |
| Hispanic (%)             | 3160 (5)           | 860 (4)   |       |
| Asian/Pacific Islander (%) | 910 (1)            | 270 (1)   |       |
| Native American (%)      | 230 (<1)           | 65 (<1)   |       |
| Other (%)                | 1085 (2)           | 340 (<1)  |       |
| Charlson Comorbidity Index Score | 16,120 (24) | 5315 (23) | 0.09 |
| 1 (%)                    | 16,120 (24)        | 5315 (23) |       |
| 2 (%)                    | 12,730 (19)        | 4545 (20) |       |
| 3 (%)                    | 8485 (13)          | 2830 (12) |       |
| >4 (%)                   | 14,955 (22)        | 5495 (24) |       |
| Mean CCI (SD)            | 1.9 (1.3)          | 2.0 (1.3) | 0.04 |
| Hypertension (%)         | 57,825 (87)        | 19,940 (88) | 0.25 |
| Diabetes mellitus (%)    | 23,370 (35)        | 8235 (36) | 0.21 |
| Heart failure (%)        | 26,225 (39)        | 9635 (42) | 0.004|
| Chronic kidney disease (%) | 15,805 (24)      | 5715 (25) | 0.11 |
| Dialysis (%)             | 1000 (2)           | 450 (2)   | 0.03 |
| Anemia (%)               | 12,485 (19)        | 4655 (20) | 0.04 |
| Liver disease (%)        | 1760 (3)           | 680 (3)   | 0.201|
| Cancer (%)               | 1450 (2)           | 545 (2)   | 0.40 |
| Prior PCI (%)            | 11,640 (17)        | 3720 (16) | 0.13 |
| Prior CABG (%)           | 9510 (14)          | 2950 (13) | 0.04 |
| Prior valve replacement (%) | 3585 (5)          | 1370 (6)  | 0.13 |
| Outcomes (Unadjusted)    |                   |          |      |
| In-hospital mortality (%)| 110 (0.2)          | 30 (0.1)  | 0.62 |
| Acute ischemic stroke (%)| 135 (0.2)          | 80 (0.4)  | 0.09 |
| Postprocedural hemorrhage (%) | 305 (0.5)      | 115 (0.5) | 0.69 |
| Percardiocentesis (%)    | 695 (1.0)          | 180 (0.8) | 0.12 |
| PRBCs transfusion (%)    | 1040 (1.6)         | 360 (1.6) | 0.94 |
| Median length of stay (IQR) | 1(1-1)            | 1(1-1)    | -0.001*|
| Mean length of stay      | 1.4                | 1.3       | 0.21 |

CABG, coronary artery bypass graft; IQR, inter-quartile range; LAAO, left atrial appendage occlusion; SD, standard deviation; PCI, percutaneous coronary intervention.

*The result is statistically significant despite similar median as higher percentage of hospitalizations in pre-COVID time had length of stay above median (13.6 % vs 11.7%).
TABLE 3. Baseline characteristics and unadjusted outcomes of TEER admissions stratified according to time of procedure (Pre and during COVID pandemic)

| Baseline characteristics                       | TEER (n = 40,160) | P Value |
|------------------------------------------------|-------------------|---------|
|                                                | Pre-pandemic (n = 30,980) | During pandemic (n = 9,180) |
| Mean age in years (SD)                         | 76.9 (9.9)        | 75.9 (9.9) | 0.001 |
| Female sex (%)                                 | 14,300 (46)       | 411 (45)  | 0.25  |
| Hospital region                                | 0.77              |          |       |
| Northeast (%)                                  | 5615 (18)         | 1465 (16) |       |
| Midwest (%)                                    | 6275 (20)         | 1765 (19) |       |
| South (%)                                      | 10,920 (35)       | 3480 (38) |       |
| West (%)                                       | 8170 (26)         | 2470 (27) |       |
| Primary payer                                  |                   |          | 0.01  |
| Medicare (%)                                   | 26,105 (84)       | 7540 (82) |       |
| Medicaid (%)                                   | 820 (3)           | 405 (4)   |       |
| Private (%)                                    | 3345 (11)         | 965 (11)  |       |
| Self-Pay (%)                                   | 165 (1)           | 60 (1)    |       |
| Other (%)                                      | 520 (2)           | 195 (2)   |       |
| Race                                           |                   |          | 0.16  |
| White (%)                                      | 23,955 (80)       | 6960 (78) |       |
| Black (%)                                      | 2500 (8)          | 930 (10)  |       |
| Hispanic (%)                                   | 1815 (6)          | 570 (6)   |       |
| Asian/Pacific Islander (%)                    | 785 (3)           | 280 (3)   |       |
| Native American (%)                            | 135 (<1)          | 25 (<1)   |       |
| Other (%)                                      | 735 (2)           | 165 (2)   |       |
| Charlson Comorbidity Index Score               |                   |          | 0.01  |
| 0 (%)                                          | 1980 (6)          | 395 (4)   |       |
| 1 (%)                                          | 6310 (20)         | 1760 (19) |       |
| 2 (%)                                          | 5765 (19)         | 1690 (18) |       |
| 3 (%)                                          | 5590 (18)         | 1790 (19) |       |
| ≥ 4 (%)                                        | 11,335 (37)       | 3545 (39) |       |
| Mean CCI (SD)                                  | 2.6 (1.2)         | 2.7 (1.2) | 0.006 |
| Hypertension (%)                               | 25,820 (83)       | 7940 (86) | 0.004 |
| Diabetes mellitus (%)                          | 8400 (27)         | 2730 (30) | 0.026 |
| Heart failure (%)                              | 26,320 (85)       | 8190 (89) | <0.001|
| Atrial fibrillation (%)                        | 18,510 (60)       | 5440 (59) | 0.71  |
| Chronic kidney disease (%)                    | 12,215 (39)       | 3725 (41) | 0.44  |
| Dialysis (%)                                   | 975 (3)           | 335 (4)   | 0.32  |
| Anemia (%)                                     | 9455 (31)         | 2420 (26) | 0.002 |
| Liver disease (%)                              | 1195 (4)          | 475 (5)   | 0.02  |
| Cancer (%)                                     | 920 (3)           | 270 (3)   | 0.95  |
| Prior PCI (%)                                  | 6140 (20)         | 1945 (21) | 0.22  |
| Prior CABG (%)                                 | 6095 (20)         | 1585 (17) | 0.03  |
| Prior valve replacement (%)                   | 2490 (8)          | 745 (8)   | 0.91  |
| Outcomes (Unadjusted)                          |                   |          |       |
| In-hospital mortality (%)                     | 630 (2.0)         | 195 (2.1) | 0.80  |
| Acute ischemic stroke (%)                     | 200 (0.6)         | 30 (0.3)  | 0.11  |
| Postprocedural hemorrhage (%)                 | 403 (1.4)         | 110 (1.2) | 0.53  |

(continued)
2.0%, aOR: 1.02 [0.71-1.45], \( P = 0.93 \), AIS (0.3% vs 0.6%, aOR: 0.49 [0.21-1.17], \( P = 0.11 \)), and post-procedural hemorrhage (1.2% vs 1.4%, aOR: 0.86 [0.54-1.36], \( P = 0.51 \)). However, mean LOS has decreased by 0.63 days (\( P = 0.01 \)). Over the study period, mean LOS decreased from 5.74 days, 95% CI (4.68-6.79) in Q1 2016 to 3.20 days, 95% CI [2.72-3.68] in Q4 2020 (Ptrend < 0.001) (Fig 3C). Median LOS decreased from 3 days (IQR: 2-7 days) in Q1 2016 to 1 day (IQR: 1-3 days) in Q4 2020 (\( P < 0.001 \)).

**Discussion**

Our study from a national database is the largest to date to evaluate the national trends of SHD interventions before and during COVID 19
pandemic in the United States till the end of 2020. We report several important findings. First, the trend of rising rates of SHD interventions was impacted by COVID-19 in the second quarter of 2020 corresponding to the initial phase of the pandemic in the United States but improved thereafter. Second, characteristics of patients that underwent TAVR during COVID-19 were different pre COVID-19 compared to during COVID-19. This difference was not seen for LAAO or TEER interventions. Third, rates of complications were not impacted by the pandemic despite shorter LOS. Fourth, LOS were reduced during COVID pandemic compared to prepandemic in TAVR and TEER but not in LAAO.

Early data on the impact of COVID-19 pandemic showed a decline in procedural rates in the US and globally. Khalili et al reported relative reduction of 58% in SHD interventions during COVID 19 in a multicenter study. Mohamed et al reported significant decline of cardiac procedure activity across England during the pandemic. In Italy, Tarantini et al

| Quarter (Q) | TAVR | LAAO | TEER |
|------------|------|------|------|
| 2016       |      |      |      |
| Q1         | 96   | 10   | 12   |
| Q2         | 115  | 13   | 14   |
| Q3         | 119  | 16   | 12   |
| Q4         | 127  | 21   | 14   |
| 2017       |      |      |      |
| Q1         | 136  | 23   | 16   |
| Q2         | 148  | 29   | 17   |
| Q3         | 148  | 35   | 18   |
| Q4         | 154  | 38   | 19   |
| 2018       |      |      |      |
| Q1         | 155  | 42   | 19   |
| Q2         | 173  | 50   | 21   |
| Q3         | 170  | 53   | 20   |
| Q4         | 173  | 57   | 24   |
| 2019       |      |      |      |
| Q1         | 182  | 65   | 27   |
| Q2         | 210  | 75   | 33   |
| Q3         | 220  | 76   | 29   |
| Q4         | 241  | 88   | 32   |
| 2020       |      |      |      |
| Q1         | 240  | 79   | 35   |
| Q2         | 220  | 57   | 31   |
| Q3         | 246  | 97   | 38   |
| Q4         | 253  | 109  | 36   |

LAAO, left atrial appendage occlusion; TAVR, transcatheter aortic valve replacement; TEER, transcatheter end-to-end repair.
FIG 3. Temporal trends of adjusted mean length of stay with 95% confidence intervals in TAVR (3A), LAAO (3B), TEER (3C). (Color version of figure is available online.)
reported 79% decline in SHD interventions. This decline was observed in our study in Q2 of 2020. However, procedural rates gained its pre-pandemic values by the Q4 of 2020. In TAVR, this decline had a negative impact on high-risk patients as shown in a small study of 77 patients where in TAVR was deferred due to the COVID-19 pandemic. In this study, up to 10% of patients experienced a cardiac event within the first month and up to 35% over the following 3 months. Elbaz-Greener et al reported an association between longer wait times for patients awaiting TAVR and increasing mortality and heart failure hospitalization.

Further, we observed no differences in the in-hospital mortality outcome and acute stroke, that was similar to studies that showed that TAVR can be safely performed during the COVID-19 pandemic, without an increased risk of complications or mortality. A study from Netherlands examined 2131 patients before and during the COVID-19 pandemic and found that the patient characteristics and outcomes after TAVR were not different during the pandemic. A single-center study in Israel compared TAVR outcomes among 270 patients before and during the COVID-19 pandemic and showed that the primary outcome revealed similar TAVR success. Another important finding in our study is the difference in baseline characteristics in patients undergoing TAVR during the pandemic in comparison to pre-pandemic. This is likely unrelated to COVID but rather the adoption of low-risk TAVR trials and Food and Drug Administration (FDA) approval of TAVR in low-risk patients in 2019.

Our study showed a decline in LAAO procedural rates in Q2 2020 which has relatively improved in Q4 2020. This could be explained by the increased rate of less invasive strategy and the increased utilization of cardiac computed tomography and intra-cardiac echo instead of transesophageal echo, which allows relatively safer intervention without general anesthesia and airway manipulation.

Unlike TAVR, there is a paucity of literature on characteristics and outcomes of patients undergoing LAAO during the pandemic which is likely secondary to non-urgency of the procedure as compared to TAVR. Our study reporting similar baseline characteristics and outcomes before and during the pandemic.

Following the same trend, TEER interventions declined in Q2 of 2020 before a relative improvement in Q4 2020. Mack et al reported an increase of TEER utilization in a retrospective analysis of STS/ American College of Cardiology TVT registry from 2014 to March 2020. In a retrospective study from England by Mohamed et al, cardiac procedural activity has significantly declined during COVID pandemic. The study did not evaluate TEER as a sole entity, but rather included with other valve replacement/
The study evaluated procedures only till May 2020. Our results are consistent with Mohamed et al’s study during that time. Another factor to consider when comparing both studies is that the above-mentioned study was done in England where the timeline of the COVID-19 pandemic was different from that in the United States. In contrast to TAVR, patients who underwent TEER during the pandemic carried a higher comorbidity burden. This is best explained by the potential benefit of reducing LOS and recurrent admissions in symptomatic heart failure patients which could have justified the risk of intervention during the pandemic as opposed to the risk of recurrent admission. In the Cardiovascular Outcomes Assessment of the MitraClip Percutaneous Therapy for Heart Failure Patients with Functional Mitral Regurgitation trial, a 50% all-cause death rate was reported at 24-month follow-up in the conservative management arm which translates to a 2% monthly fatality rate unless TEER is instituted early in patients with severe symptomatic MR.

The COVID-19 pandemic necessitated many changes in standard medical practice, requiring healthcare systems to adapt and find innovative solutions to reduce the spread of infection. Our analysis showed that the admissions during COVID-19 had lower mean and median LOS compared to pre-pandemic admissions in TAVR and TEER but remained stable in LAAO. Moreover, there has been a continuous trend of decreased LOS before the pandemic which implies that the decreased LOS could be a result of improvement and natural progression rather than a direct result of the pandemic. However, we believe that COVID has stimulated changes in health care system such as adoption of same day discharge in certain procedures. A study on 124 of 2100 patients showed that same discharge post TAVR procedure was safe and feasible in selected patients along with a low risk of post procedure complications including stroke, requirement of pacemaker. Another case series of 6 patients showed successful TAVR with same day discharge using telemedicine follow up. A case series of same-day discharge after TEER found that it was feasible with close follow up and careful patient selection. Along the same line, same day discharge for LAAO was established before the COVID-19 pandemic. A prior nationwide study that showed increased rates of same day discharge in the US from 2016 to 2019. However, its largescale adoption was observed during the COVID-19 pandemic.

Limitations

Our study has certain limitations. First, this is a retrospective study which is subject to residual confounding bias. Second, the administrative
nature of the database and reliance on ICD-10-CM codes makes it prone to coding bias. However, procedural codes are less likely to be miscoded. Third, the lack of granular data such as laboratory work-up and echocardiographic findings precludes including them in statistical adjustment. Fourth, the NIS database is limited to index hospitalizations and thus, out-of-hospital or readmission outcomes could not be evaluated which is an area for future research. Last, lack of 2021 data which would have provided more information on the change of practices and policies during the vaccination era. NIS 2021 is not currently available.

**Conclusion**

This nationwide analysis showed that SHD interventions decreased during the early waves of COVID-19 pandemic. While there was a significant reduction in hospital LOS during the COVID-19 pandemic, there were no differences in in-hospital mortality or complication rates. The unprecedented challenges brought on by the pandemic necessitated innovative methods to effectively triage patients for procedures, decrease hospital LOS, utilize fewer resources in an already strained healthcare environment, that allowed access to SHD intervention for more candidates without affecting the safety of performing such procedures during the pandemic.

**Credit Author Statement**

Ahmed Maraey: Conceptualization, methodology, formal analysis, writing-original draft, writing-review and editing; Kashvi Gupta: Writing-original draft, writing-review and editing; Wael Abdelmotaleb: Writing-original draft; mahmoud khalil: writing-original draft; Waqas Ullah: Conceptualization, writing-review and editing; Alexander G. Hajduczok: Conceptualization, writing-review and editing; Hadeer Elsharnoby: visualization, writing-15 review and editing; Ahmed Elzanaty: Writing-review and editing; Islam Y. Elgendy: Writing, review and editing, supervision.

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