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STRUCTURAL

Impact of the COVID-19 Pandemic on Global TAVR Activity

The COVID-TAVI Study

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ABSTRACT

BACKGROUND The COVID-19 pandemic adversely affected health care systems. Patients in need of transcatheter aortic valve replacement (TAVR) are especially susceptible to treatment delays.

OBJECTIVES This study sought to evaluate the impact of the COVID-19 pandemic on global TAVR activity.

METHODS This international registry reported monthly TAVR case volume in participating institutions prior to and during the COVID-19 pandemic (January 2018 to December 2021). Hospital-level information on public vs private, urban vs rural, and TAVR volume was collected, as was country-level information on socioeconomic status, COVID-19 incidence, and governmental public health responses.

RESULTS We included 130 centers from 61 countries, including 65,980 TAVR procedures. The first and second pandemic waves were associated with a significant reduction of 15% ($P < 0.001$) and 7% ($P < 0.001$) in monthly TAVR case volume, respectively, compared with the prepandemic period. The third pandemic wave was not associated with reduced TAVR activity. A greater reduction in TAVR activity was observed in Africa (−52%; $P = 0.001$), Central-South America (−33%; $P < 0.001$), and Asia (−29%; $P < 0.001$). Private hospitals ($P = 0.005$), urban areas ($P = 0.011$), low-volume centers ($P = 0.002$), countries with lower development ($P < 0.001$) and economic status ($P < 0.001$), higher COVID-19 incidence ($P < 0.001$), and more stringent public health restrictions ($P < 0.001$) experienced a greater reduction in TAVR activity.

CONCLUSIONS TAVR procedural volume declined substantially during the first and second waves of the COVID-19 pandemic, especially in Africa, Central-South America, and Asia. National socioeconomic status, COVID-19 incidence, and public health responses were associated with treatment delays. This information should inform public health policy in case of future global health crises. (J Am Coll Cardiol Intv 2024;17:374–387) © 2024 by the American College of Cardiology Foundation.

ABBREVIATIONS AND ACRONYMS

ACS = acute coronary syndrome

GDP = gross domestic product

GNI = gross national income

HDI = Human Development Index

IRR = incidence rate ratio

SARS-CoV-2 = severe acute respiratory syndrome-coronavirus-2

SAVR = surgical aortic valve replacement

TAVR = transcatheter aortic valve replacement

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The COVID-19 pandemic rapidly overwhelmed health care systems around the world. Health care resources were redirected to manage fallout from the emerging pandemic and established care pathways for many acute and chronic diseases were suspended. Public health messaging encouraged populations to stay at home and travel restrictions were enforced to limit contagion. Such actions were associated with reduced hospitalization for and increased mortality from cardiovascular diseases.[1,2] For example, hospital admission for acute coronary syndromes (ACS) and activation of ST-segment elevation myocardial infarction pathways were reduced.[3,4]

The COVID-19 pandemic likely had a negative impact on patients with valvular heart disease as well.[5,6] Patients with symptomatic severe aortic valve stenosis necessitating surgical aortic valve replacement (SAVR) or transcatheter aortic valve replacement (TAVR) are especially vulnerable to treatment delays, and treatment deferral is associated with an increased risk of hospitalization and death.[5,6] It is therefore concerning that single center and regional reports have suggested reduced TAVR procedural volume during the COVID-19 pandemic.[7,8] The impact of the COVID-19 pandemic on a specific procedure such as TAVR, however, is likely to have been heterogeneous across diverse countries and health care systems, and has been influenced by socioeconomic and other national factors, the incidence of severe acute respiratory syndrome coronavirus 2

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

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CENTRAL ILLUSTRATION Global TAVR Activity Before and During the COVID-19 Pandemic

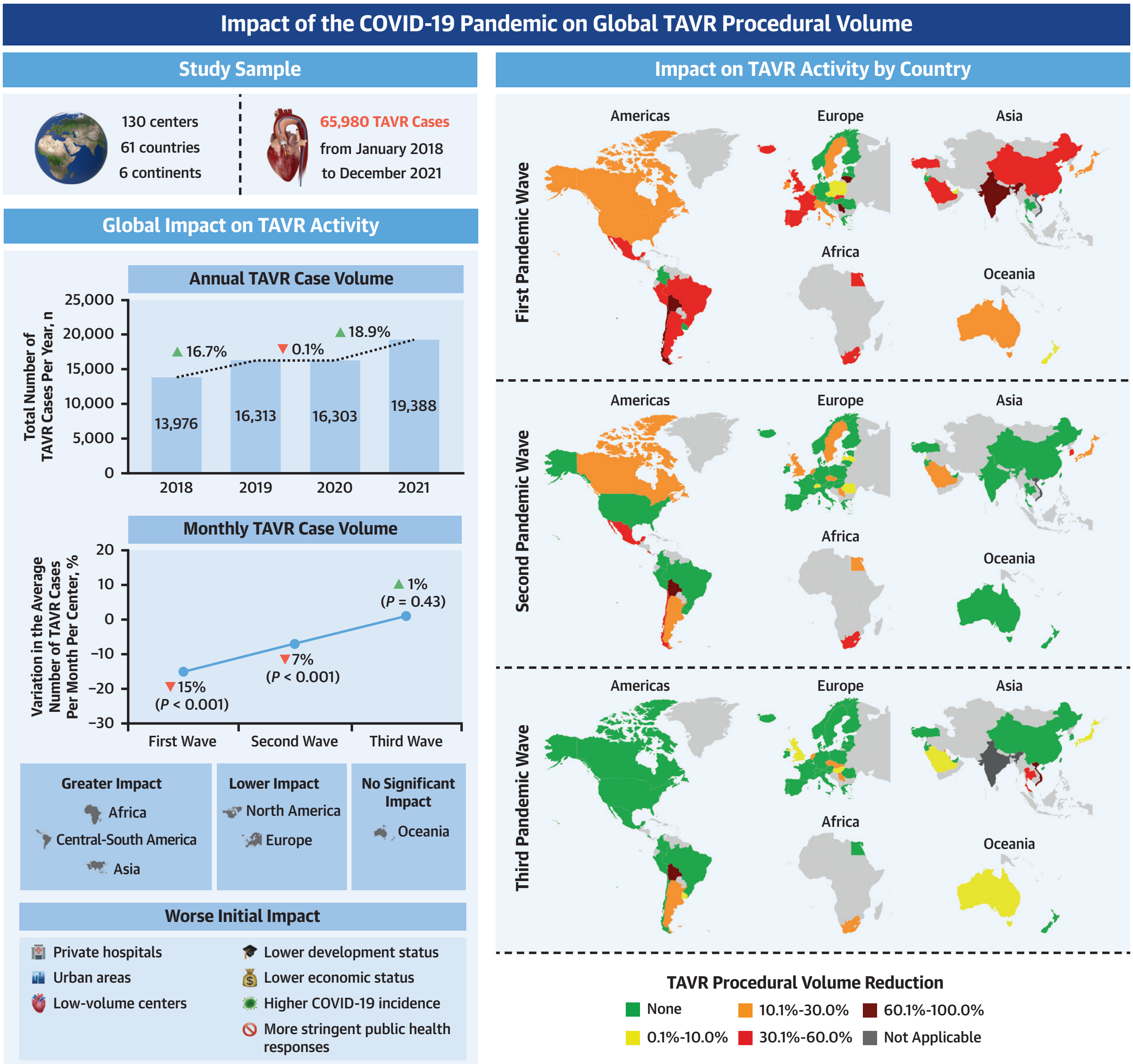

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TABLE 1 Center Characteristics and TAVR Activity During the Period 2018-2021

	Europe (n = 66)	Asia (n = 32)	America: Central-South (n = 18)	America: North (n = 8)	Oceania (n = 4)	Africa (n = 2)	Global (n = 130)
Center characteristics							
Health care system							
Public	58 (87.9)	20 (62.5)	7 (38.9)	5 (62.5)	2 (50.0)	1 (50.0)	93 (71.5)
Private	6 (9.1)	11 (34.4)	10 (55.6)	3 (37.5)	1 (25.0)	1 (50.0)	32 (24.6)
Mixed	2 (3.0)	1 (3.1)	1 (5.6)	0 (0.0)	1 (25.0)	0 (0.0)	5 (3.8)
Demographic status							
Urban	52 (78.8)	29 (90.6)	17 (94.4)	6 (75.0)	3 (75.0)	1 (50.0)	108 (83.1)
Rural	14 (21.2)	3 (9.4)	1 (5.6)	2 (25.0)	1 (25.0)	1 (50.0)	22 (16.9)
TAVR volume							
Low	9 (13.6)	18 (56.3)	16 (88.9)	1 (12.5)	0 (0.0)	1 (50.0)	45 (34.6)
Intermediate	19 (28.8)	6 (18.8)	2 (11.1)	1 (12.5)	1 (25.0)	1 (50.0)	30 (23.1)
High	38 (57.6)	8 (25.0)	0 (0.0)	6 (75.0)	3 (75.0)	0 (0.0)	55 (42.3)
Development status							
HDI	0.912 ± 0.035	0.847 ± 0.087	0.801 ± 0.041	0.927 ± 0.002	0.941 ± 0.007	0.708 ± 0.001	0.879 ± 0.071
Economic status							
GDP per capita, $	49,363 ± 14,954	40,988 ± 24,030	19,718 ± 4,953	59,171 ± 8,175	50,200 ± 3,097	13,274 ± 1,435	43,307 ± 19,603
GNI per capita, $	47,991 ± 12,599	41,089 ± 23,341	18,979 ± 4,665	59,576 ± 9,031	48,675 ± 2,830	12,870 ± 1,499	42,490 ± 18,472
COVID-19 incidence[a]							
First wave	0.94 ± 0.85	1.39 ± 2.63	3.18 ± 2.43	1.89 ± 1.12	0.09 ± 0.09	0.75 ± 1.03	1.61 ± 2.05
Second wave	7.01 ± 5.96	2.25 ± 3.05	5.17 ± 2.53	6.95 ± 5.59	0.12 ± 0.11	1.59 ± 2.25	5.73 ± 5.52
Third wave	8.06 ± 7.08	3.74 ± 5.79	7.40 ± 6.27	7.40 ± 3.99	1.19 ± 0.87	1.94 ± 2.69	6.35 ± 6.67
COVID-19 stringency index							
First wave	36.0 ± 12.7	29.5 ± 18.1	40.0 ± 9.6	33.1 ± 2.6	31.2 ± 13.9	36.9 ± 12.0	35.1 ± 13.6
Second wave	24.6 ± 14.6	20.3 ± 16.8	29.6 ± 13.0	29.5 ± 8.5	26.8 ± 15.1	18.5 ± 9.2	24.9 ± 14.5
Third wave	26.8 ± 16.0	21.3 ± 13.9	21.8 ± 14.7	21.6 ± 8.9	34.1 ± 8.4	12.0 ± 9.8	24.3 ± 15.1
Annual TAVR procedural volume							
2018-2019							
TAVR cases in 2018	9,839	2,000	443	1,275	345	74	13,976
TAVR cases in 2019	11,670	2,154	479	1,431	499	80	16,313
Absolute variation	1,831	154	36	156	154	6	2,337
Relative variation, %	18.6	7.7	8.1	12.2	44.6	8.1	16.7
2019-2020							
TAVR cases in 2019	11,670	2,154	479	1,431	499	80	16,313
TAVR cases in 2020	11,919	2,065	386	1,331	555	47	16,303
Absolute variation	249	−89	−93	−100	56	−33	−10
Relative variation, %	2.1	−4.1	−19.4	−7.0	11.2	−41.3	−0.1
2020-2021							
TAVR cases in 2020	11,919	2,065	386	1,331	555	47	16,303
TAVR cases in 2021	13,596	2,990	570	1,605	548	79	19,388
Absolute variation	1,677	925	184	274	−7	32	3,085
Relative variation, %	14.1	44.8	47.7	20.6	−1.3	68.1	18.9

Values are n (%) or mean ± SD unless otherwise indicated. [a]COVID-19 incidence is reported as the monthly number of COVID-19 cases per thousand inhabitants.
GDP = gross domestic product; GNI = gross national income; HDI = Human Development Index; TAVR = transcatheter aortic valve replacement.

(SARS-CoV-2) infection, and the severity of governmental public health measures introduced in response to the pandemic.

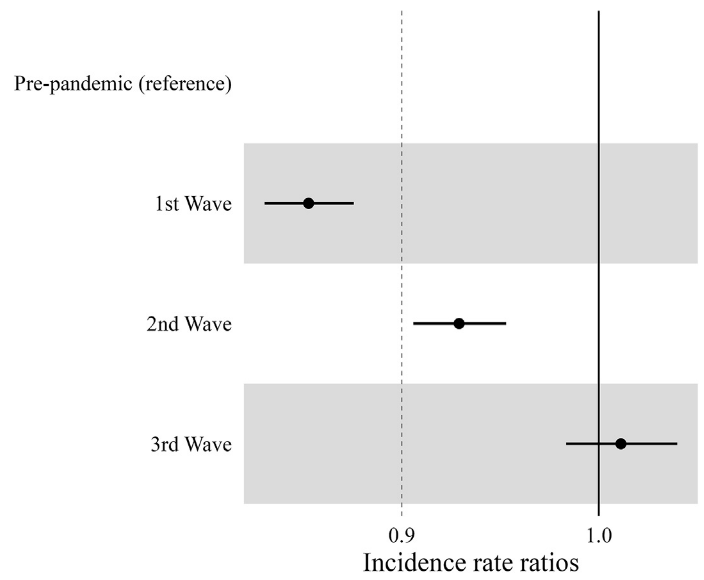
Herein, we present the results of the COVID-TAVI (coronavirus disease - transcatheter aortic valve implantation) study detailing the impact of the COVID-19 pandemic on global TAVR activity, including a wide range of countries with distinct health care systems and demographic, development, and economic statuses.

METHODS

STUDY DESIGN. We undertook an investigator-initiated, multinational, retrospective study to create a registry on global TAVR activity before and during the COVID-19 pandemic. Individual TAVR centers were invited to voluntarily participate in the study. Centers were identified from a variety of sources: existing collaborative research projects, National Library of Medicine (PubMed) publications, international cardiovascular congresses, and national cardiovascular websites. We invited 292 centers, of which 162 (55.5%) responded and finally 130 (44.5%) submitted the required data.

We collected monthly TAVR case volume at each site prior to and during the COVID-19 pandemic (January 2018 to December 2021) using a dedicated report template. Regional and national demographic (population size and density), development (Human Development Index [HDI]) and economic data (gross domestic product [GDP] per capita and gross national income [GNI] per capita), COVID-19 incidence, and governmental public health responses to the pandemic were also recorded. The study was approved by the ethics committee at Galway University Hospital and was conducted in accordance with the Declaration of Helsinki.

FIGURE 1 COVID-19 Pandemic Waves



The coefficients of each COVID-19 pandemic wave term report the incidence rate ratio (IRR) of transcatheter aortic valve replacement (TAVR) procedures per month during each of the pandemic waves compared with prepandemic months. An IRR <1 suggests a reduction in the rate of TAVR compared with prepandemic months, while an IRR >1 suggests an increase in the rate of TAVR compared with prepandemic months.

ENDPOINTS AND DEFINITIONS. The objectives of this study were: 1) to assess the association of the COVID-19 pandemic with global TAVR procedural volume; 2) to study if the COVID-19 pandemic differentially impacted TAVR procedural volume according to geographic region, health care system, demographic, development, or economic status; and 3) to evaluate if the incidence of SARS-CoV-2 infection or the stringency of governmental public health measures impacted TAVR procedural volume.

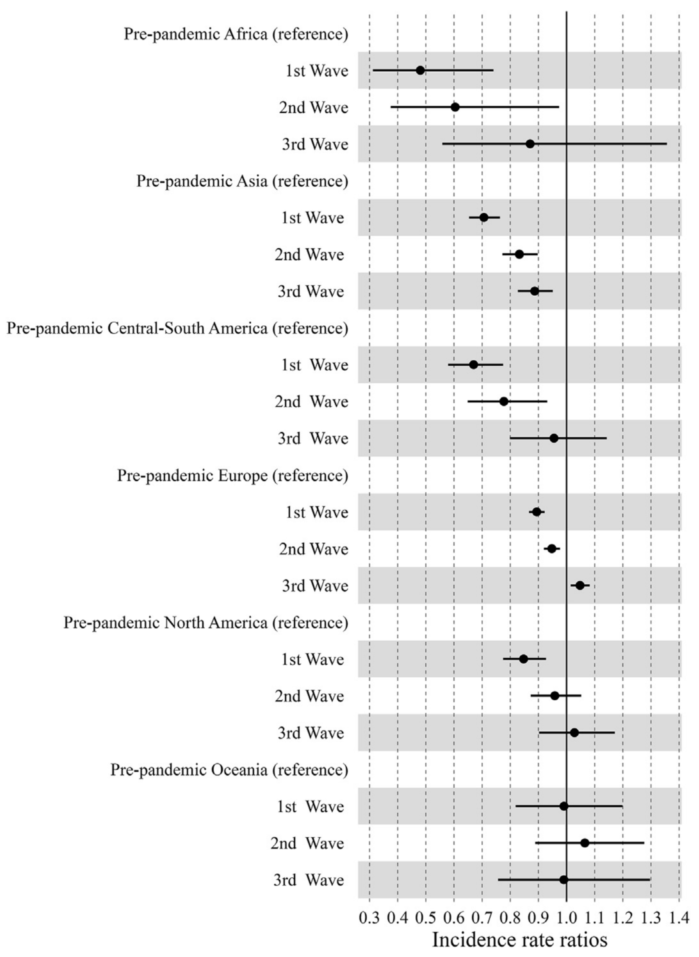
The primary outcome of interest was the monthly variation in the average number of TAVR cases per center performed between January 2018 and December 2021. We defined the prepandemic period between January 2018 and the start of the COVID-19 pandemic. The pandemic period extended from the start of the pandemic until December 2021. We sought to assess the impact of sequential waves of the COVID-19 pandemic on TAVR volume during the study period, as differential responses to managing the effect of the pandemic on health care were evident globally.[9] Such responses could potentially mitigate, or exacerbate, the impact of a pandemic wave on TAVR volume. The start of the COVID-19 pandemic and the delineation of the pandemic waves were defined by country. Several definitions of COVID-19 pandemic wave exist but most have been focused on a specific country and do not readily apply to other jurisdictions.[10,11] In our study, a pandemic wave was arbitrarily defined as the time period between a significant (multiplication or division by at least 2) and sustained (duration of at least 1 month) increase and decrease in the weekly number of

TABLE 2 COVID-19 Pandemic Waves

	Variation in the Average Number of TAVR Cases per Month per Center		
	Rate (95% CI)	IRR (95% CI)	*P* Value
Prepandemic period	10.46 (8.19-12.72)	NA	NA
First wave	NA	0.85 (0.83-0.88)	<0.001
Second wave	NA	0.93 (0.91-0.95)	<0.001
Third wave	NA	1.01 (0.98-1.04)	0.43

IRR = incidence rate ratio; NA = not applicable; TAVR = transcatheter aortic valve replacement.

FIGURE 2 Geographic Region



The coefficients of each COVID-19 pandemic wave term report the IRR of TAVR procedures per month during each of the pandemic waves compared with prepandemic months. An IRR <1 suggests a reduction in the rate of TAVR compared with prepandemic months, while an IRR >1 suggests an increase in the rate of TAVR compared with prepandemic months. Abbreviations as in Figure 1.

COVID-19 cases per million people, regardless of the number of peaks within this time period (Supplemental Table 1).[12] The monthly variation in the average number of TAVR cases per center was analyzed during each pandemic wave and was compared with the prepandemic period.

Geographic regions included country and continent, each defined according to the United Nations Statistics Division based on the standard country or area codes for statistical use M49.[13] Participating centers self-reported their activity as public, private, or mixed. Centers were also classified as urban or rural according to the United Nations Statistical Commission criteria based on the population size and density.[14] Considering the self-reported total number of TAVR procedures performed in 2019, centers were classified as low-volume (<50 TAVRs/y), intermediate-volume (50-100 TAVRs/y), or high-volume (>100 TAVRs/y) centers.[15] The development status of countries was defined according to the United Nations Development Program criteria using the HDI,[16] and economic status was defined according to the World Bank criteria using the GDP per capita and GNI per capita, based on purchasing power parity.[17] All demographic, development, and economic data were collected from 2019, prior to the onset of the COVID-19 pandemic.

The COVID-19 incidence was reported as the monthly number of COVID-19 cases per 1,000 inhabitants from the Our World in Data project, a collaboration between the Oxford Martin Program on Global Development (University of Oxford, United Kingdom) and the Global Change Data Lab.[12] Governmental public health policies implemented by each country to mitigate the health and social impacts of the COVID-19 pandemic were defined according to the Oxford Coronavirus Government Response Tracker, which grades the severity of these measures using the COVID-19 stringency index.[18] This composite measure ranges from 0 (most lenient) to 100 (most strict) and is based on 9 response indicators, such as school/workplace closures and travel bans (Supplemental Table 2).

STATISTICAL ANALYSIS. To account for within-center and within-country clustering, we used a 3-level Poisson mixed model, with repeated measures of TAVR procedures treated as counts clustered within centers, which themselves are clustered within countries. A categorical variable that denoted the COVID-19 pandemic wave number was included, with prepandemic months set as the reference category, and pandemic waves 1, 2, and 3 allocated as defined previously. Because all countries were modelled together, it was not necessary for every country to experience 3 pandemic waves. The coefficients of each COVID-19 pandemic wave term report the incidence rate ratio (IRR) of TAVR procedures per month during each of the pandemic waves compared with prepandemic months. An IRR <1 suggests a reduction in the rate of TAVR compared with prepandemic months, while an IRR >1 suggests an increase in the rate of TAVR compared with prepandemic months. We included random intercepts for centers within countries. Given the wide disparities between continents, we used mixed models for each continent separately, alongside the primary worldwide model, to investigate regional changes in TAVR activity during the COVID-19 pandemic. We then investigated the potential effect of country-level variables: health care system, demographic status, development status, economic status, COVID-19 incidence, and governmental public health responses. Because many of these variables were highly correlated, we used separate models for each variable individually alongside the time and pandemic wave variables. An interaction term between each country-level variable and pandemic wave was included to assess whether these variables were associated with a better or worse impact of COVID-19 on TAVR activity. The IRR for interaction terms is not for comparison with prepandemic months, but instead is for comparison with the reference category of the country-level factor (eg, private hospitals). Statistical significance was defined as a *P* value ≤0.05. All statistical analysis was performed using R, version 4.1 (R Foundation for Statistical Computing).

TABLE 3 Geographic Region

	Variation in the Average Number of TAVR Cases per Month per Center		
	Rate (95% CI)	IRR (95% CI)	P Value
Africa			
Prepandemic period	2.00 (0.04-3.96)	NA	NA
First wave	NA	0.48 (0.31-0.74)	0.001
Second wave	NA	0.60 (0.38-0.97)	0.038
Third wave	NA	0.87 (0.56-1.36)	0.54
America, Central-South			
Prepandemic period	1.22 (0.49-1.96)	NA	NA
First wave	NA	0.67 (0.58-0.77)	<0.001
Second wave	NA	0.78 (0.65-0.93)	0.006
Third wave	NA	0.96 (0.80-1.14)	0.62
America, North			
Prepandemic period	15.62 (9.19-22.06)	NA	NA
First wave	NA	0.85 (0.77-0.93)	<0.001
Second wave	NA	0.96 (0.87-1.05)	0.37
Third wave	NA	1.03 (0.90-1.17)	0.68
Asia			
Prepandemic period	5.48 (3.48-7.49)	NA	NA
First wave	NA	0.71 (0.65-0.76)	<0.001
Second wave	NA	0.83 (0.77-0.90)	<0.001
Third wave	NA	0.89 (0.83-0.95)	0.001
Europe			
Prepandemic period	15.17 (11.36-18.97)	NA	NA
First wave	NA	0.89 (0.87-0.92)	<0.001
Second wave	NA	0.95 (0.92-0.98)	<0.001
Third wave	NA	1.05 (1.01-1.08)	0.005
Oceania			
Prepandemic period	6.75 (3.23-10.27)	NA	NA
First wave	NA	0.99 (0.82-1.20)	0.92
Second wave	NA	1.07 (0.89-1.28)	0.50
Third wave	NA	0.99 (0.76-1.30)	0.94

Abbreviations as in Table 2.

RESULTS

We collected data from 130 TAVR centers in 61 countries across 6 continents, including 65,980 TAVR procedures during the study period (**Central Illustration**). Centers were European (n = 66 [50.8%]), Asian (n = 32 [24.6%]), Central-South American (n = 18 [13.8%]), North American (n = 8 [6.2%]), Oceanic (n = 4 [3.1%]), or African (n = 2 [1.5%]) (**Table 1**). Participating TAVR centers were primarily public (n = 93 [71.5%]) and urban (n = 108 [83.1%]), and were categorized as low volume (n = 45 [34.6%]), intermediate volume (n = 30 [23.1%]) and high volume (n = 55 [42.3%]), respectively.

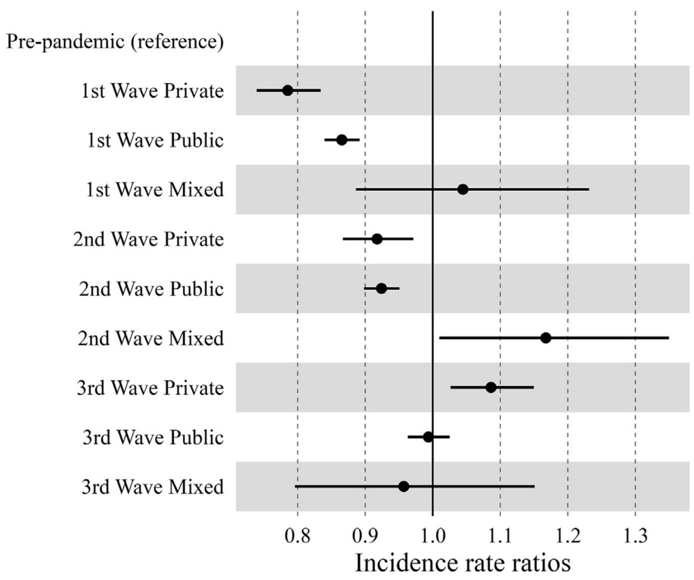
In the year prior to the COVID-19 pandemic (2019 vs 2018), annual TAVR procedural volume increased among participating centers by 16.7% (2,337 procedures) (**Table 1**). In contrast, no growth in annual TAVR procedural volume was observed after the outbreak of the COVID-19 pandemic in 2020 compared with 2019 (decrease of 0.1%; 10 procedures). Annual TAVR procedural volume increased again by 18.9% (3,085 procedures) in 2021 compared with 2020 (Supplemental Table 3).

COVID-19 PANDEMIC WAVES. Within the study period, at least 3 distinct waves of COVID-19 pandemic could be identified in all countries, except in India, where only 2 waves were observed (Supplemental Table 1).

During the first and second pandemic waves, there was a significant reduction of 15% (IRR: 0.85; 95% CI: 0.83-0.88; *P* < 0.001) and 7% (IRR: 0.93; 95% CI: 0.91-0.95; *P* < 0.001) in overall monthly TAVR procedural volume, respectively, compared with the prepandemic period (**Figure 1**, **Table 2**, Supplemental Table 4). The third pandemic wave was not associated with a significant reduction in overall TAVR activity compared with the prepandemic period (IRR: 1.01; 95% CI: 0.98-1.04; *P* = 0.43).

GEOGRAPHIC REGION. During the first pandemic wave, a numerically greater reduction of TAVR activity was observed in Africa (−52%; IRR: 0.48; 95% CI: 0.31-0.74; *P* = 0.001), Central-South America (−33%; IRR: 0.67; 95% CI: 0.58-0.77; *P* < 0.001), and Asia (−29%; IRR: 0.71; 95% CI: 0.65-0.76; *P* < 0.001),

FIGURE 3 Health Care System



The coefficients of each COVID-19 pandemic wave term report the IRR of TAVR procedures per month during each of the pandemic waves compared with prepandemic months. An IRR <1 suggests a reduction in the rate of TAVR compared with prepandemic months, while an IRR >1 suggests an increase in the rate of TAVR compared with prepandemic months. Abbreviations as in Figure 1.

compared with North America (−15%; IRR: 0.85; 95% CI: 0.77-0.93; P < 0.001) or Europe (−11%; IRR: 0.89; 95% CI: 0.87-0.92; P < 0.001) (Figure 2) (Table 3). TAVR activity was unchanged during the first pandemic wave in Oceania (−1%; IRR: 0.99; 95% CI: 0.82-1.20; P = 0.92). A similar, yet lower magnitude, impact was observed during the second pandemic wave. The third pandemic wave was associated with a significant reduction of TAVR activity only in Asia (−11%; IRR: 0.89; 95% CI: 0.83-0.95; P = 0.001) and a significant increase in Europe (+5%; IRR: 1.05; 95% CI: 1.01-1.08; P = 0.005).

HEALTH CARE SYSTEM, DEMOGRAPHIC STATUS, AND TAVR VOLUME. During the first pandemic wave, private health centers experienced a greater reduction of TAVR activity compared with public centers (P = 0.005) (Figure 3, Table 4). Conversely, the third pandemic wave saw private centers experience a greater increase of TAVR activity than public centers (P = 0.005).

Urban centers experienced a greater reduction of TAVR activity compared with rural centers (P = 0.011) during the first pandemic wave (Figure 4). No significant variation in TAVR activity between urban and rural centers was observed in subsequent waves.

Low-volume centers experienced a greater reduction of TAVR activity compared with high-volume centers (P = 0.002) in the first pandemic wave (Figure 5). In contrast, low-volume centers experienced a greater increase of TAVR activity compared with high-volume centers (P < 0.001) during the third pandemic wave.

DEVELOPMENT AND ECONOMIC STATUSES. The impact of the COVID-19 pandemic on reducing TAVR activity was more substantial in countries with lower development and economics statuses (Table 5). Indeed, during the first pandemic wave, for every 1% increase of HDI, the reduction of TAVR procedural volume was attenuated by 2% (IRR: 1.02; 95% CI: 1.02-1.03; P < 0.001), and for every $10,000 increase of GDP per capita and GNI per capita, there was an attenuation of 5% (IRR: 1.05; 95% CI: 1.03-1.07; P < 0.001). These indices did not impact TAVR procedural volumes in subsequent pandemic waves.

COVID-19 INCIDENCE AND GOVERNMENTAL PUBLIC HEALTH RESPONSE. The impact of the COVID-19 pandemic on TAVR activity was greater in countries with higher COVID-19 incidence (Table 6). During the first pandemic wave, for every COVID-19 case per 1,000 inhabitants, the reduction in TAVR procedural volume was accentuated by 8% (IRR: 0.92; 95% CI: 0.90-0.94; P < 0.001). This association was not observed in subsequent pandemic waves.

Countries with more stringent governmental public health responses to the COVID-19 pandemic also had a greater impact on TAVR activity, and this association persisted throughout the 3 pandemic waves of the study period (Table 6). For every 10% of COVID-19 stringency index, the reduction in TAVR procedural volume was accentuated by 9% (IRR: 0.91; 95% CI: 0.89-0.92; P < 0.001), 4% (IRR: 0.96; 95% CI: 0.94-0.98; P < 0.001), and 2% (IRR: 0.98; 95% CI: 0.96-1.00; P = 0.018) during the first, second, and third pandemic waves, respectively.

DISCUSSION

We present an international registry of TAVR activity during the COVID-19 pandemic. The salient results are: 1) global TAVR activity was considerably reduced during the first pandemic wave, but it gradually recovered and reached the prepandemic activity during the third pandemic wave; 2) the impact of the COVID-19 pandemic on TAVR activity was more pronounced in Africa, Central-South America, and Asia than in North America or Europe, with no significant impact in Oceania; and 3) the impact of the COVID-19 pandemic on TAVR activity was initially more profound in private hospitals, urban areas, low-volume centers, and in countries with lower development and economic statuses, higher COVID-19 incidence, and more stringent governmental public health responses.

The initial reduction in TAVR activity in response to the COVID-19 pandemic can largely be explained by 3 related factors: 1) health care systems were initially overwhelmed with COVID-19 patients and hospital resources were focused on these cases; 2) patients were reluctant to attend health care centers due to fear of contagion; and 3) public health measures encouraged or enforced populations to stay at home.[7] The gradual recovery and ultimately return to prepandemic TAVR volume suggests that health care systems and patients adapted to the new reality in the era of the COVID-19 pandemic. The availability of personal protective equipment such as face masks reduced in-hospital transmission of SARS-CoV-2 and allowed some urgent care pathways to resume.[19] The development and rollout of vaccine programs against SARS-CoV-2,[20] the emergence of community immunity to SARS-CoV-2,[21] and the arrival of new variants of SARS-CoV-2[22] all contributed to the normalization of health care pathways and return to prepandemic TAVR volume during the third pandemic wave in our study. A similar pattern of initial reduction and subsequent normalization of case volume during the COVID-19 pandemic was reported in the setting of ACS.[9]

The magnitude of the reduction in TAVR volume during the first pandemic wave was modest overall, but it was much more profound in Africa, Central-South America, and Asia. These findings are in line with a lower impact on ST-segment elevation myocardial infarction activity reported across North America and Europe during the COVID-19 pandemic.[7] While several factors could influence this observation, many countries in these regions have both low development and economic statuses. Supporting this hypothesis, we observed a clear association between the TAVR volume reduction in the first pandemic wave and the national HDI and GDP/GNI per capita. The current study is not the first to document a significant disparity in cardiovascular care and variable penetrance of novel therapies, such as TAVR, according to the national socioeconomic status, regardless of the COVID-19 pandemic.[23-25] Considering that middle- and low-income countries represent the 80% of the worldwide population,[26] these findings are concerning.

Countries with higher COVID-19 incidence and more stringent public health responses showed a greater reduction in TAVR activity in the current study. Although a correlation between COVID-19 incidence and ACS admission rate has been suggested,[27] the role of lockdown policy stringency on

TABLE 4 Health Care System, Demographic Status, and TAVR Volume

	Variation in the Average Number of TAVR Cases per Month per Center		
	Rate (95% CI)	IRR (95% CI)	*P* Value
Health care system (public vs mixed vs private)			
Prepandemic period (private)	7.38 (3.09-11.66)	NA	NA
First wave			
Private (reference)	NA	0.79 (0.74-0.83)	<0.001
Public vs private	NA	1.10 (1.03-1.18)	0.005
Mixed vs private	NA	1.33 (1.12-1.59)	0.001
Second wave			
Private (reference)	NA	0.92 (0.87-0.97)	0.003
Public vs private	NA	1.01 (0.95-1.07)	0.83
Mixed vs private	NA	1.27 (1.09-1.49)	0.002
Third wave			
Private (reference)	NA	1.33 (1.12-1.59)	0.001
Public vs private	NA	0.91 (0.86-0.97)	0.005
Mixed vs private	NA	0.88 (0.73-1.07)	0.20
Demographic status (urban vs rural)			
Prepandemic period (rural)	9.73 (5.10-14.35)	NA	NA
First wave			
Rural (reference)	NA	0.92 (0.86-0.98)	0.014
Urban vs rural	NA	0.91 (0.85-0.98)	0.011
Second wave			
Rural (reference)	NA	0.97 (0.91-1.03)	0.31
Urban vs rural	NA	0.95 (0.89-1.02)	0.15
Third wave			
Rural (reference)	NA	1.07 (1.00-1.14)	0.05
Urban vs rural	NA	0.94 (0.87-1.01)	0.08
TAVR volume (low vs intermediate vs high)			
Prepandemic period (high)	19.73 (15.61-23.84)	NA	NA
First wave			
High (reference)	NA	0.88 (0.85-0.91)	<0.001
Intermediate vs high	NA	0.90 (0.83-0.97)	0.006
Low vs high	NA	0.86 (0.79-0.95)	0.002
Second wave			
High (reference)	NA	0.92 (0.90-0.95)	<0.001
Intermediate vs high	NA	1.01 (0.94-1.08)	0.83
Low vs high	NA	1.08 (0.99-1.18)	0.10
Third wave			
High (reference)	NA	0.86 (0.79-0.95)	0.002
Intermediate vs high	NA	0.99 (0.92-1.07)	0.81
Low vs high	NA	1.23 (1.13-1.34)	<0.001

Abbreviations as in Table 2.

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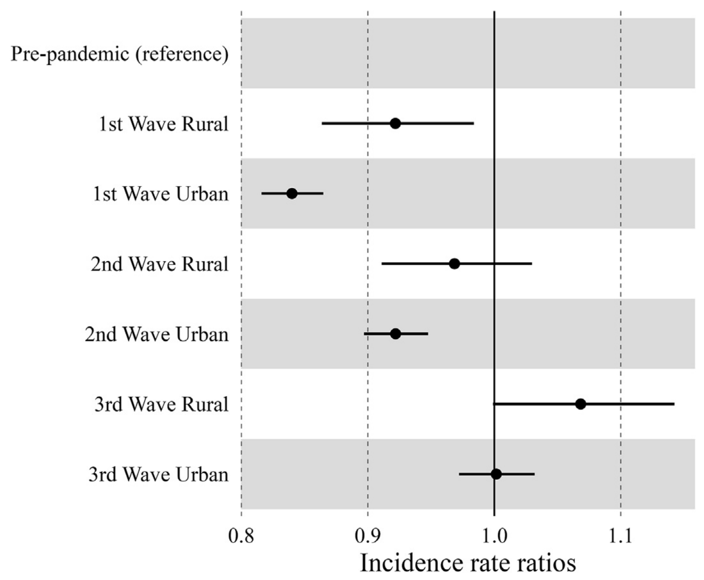
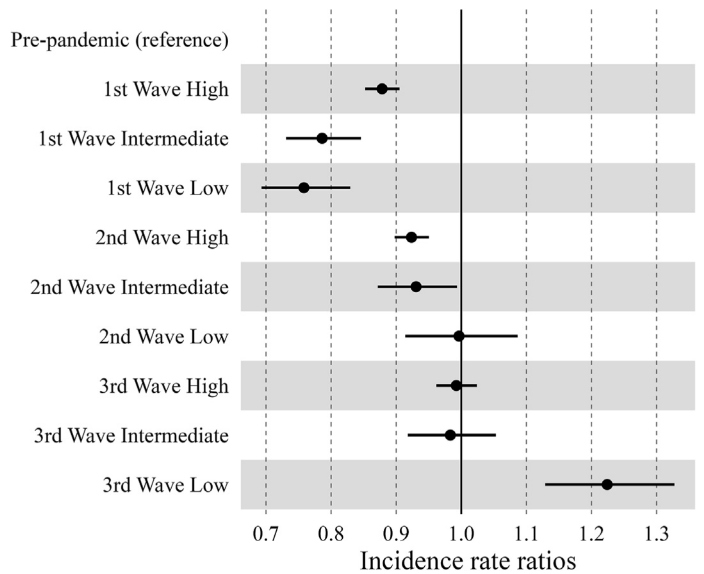
FIGURE 4 Demographic Status



The coefficients of each COVID-19 pandemic wave term report the IRR of TAVR procedures per month during each of the pandemic waves compared with prepandemic months. An IRR <1 suggests a reduction in the rate of TAVR compared with prepandemic months, while an IRR >1 suggests an increase in the rate of TAVR compared with prepandemic months. Abbreviations as in Figure 1.

FIGURE 5 TAVR Volume



The coefficients of each COVID-19 pandemic wave term report the IRR of TAVR procedures per month during each of the pandemic waves compared with prepandemic months. An IRR <1 suggests a reduction in the rate of TAVR compared with prepandemic months, while an IRR >1 suggests an increase in the rate of TAVR compared with prepandemic months. Abbreviations as in Figure 1.

cardiovascular care during the pandemic had not previously been established. While the application of containment measures, including school and workplace closures and restrictions on public gatherings, are known to reduce the transmission of the SARS-CoV-2 infection,[28,29] it is important to recognize the undesirable effects of these policies.

This information should inform World Health Organization and national public health policy in case of future global health crises. Established care pathways for high risk cardiovascular and other diseases should continue uninterrupted as reasonably achievable. Public health messaging should reinforce the importance of maintaining scheduled cardiovascular care, and health care systems should be assessed for and developed to become pandemic-resilient. Health care inequality continues to occur along socioeconomic, political, and ethnic lines, and appears to have been magnified during the COVID-19 pandemic. Addressing the social determinants of this inequity should be an important tenet of strategies to improve global health.

STUDY LIMITATIONS. Individual TAVR centers were invited to voluntarily participate in the study and may not be representative of TAVR centers globally. We were unable to identify TAVR centers in some countries, and national TAVR procedural volume during the COVID-19 pandemic is derived from a small sample size in several countries. While the results presented here for TAVR activity during the third pandemic wave may represent a return to normal prepandemic activities, they may also reflect the process of catching up on TAVR procedures that were cancelled or delayed earlier in the pandemic. For the purposes of clarity, we reported continent-level data, acknowledging that each continent includes a wide variety of different countries with heterogeneous socioeconomic data. Therefore, findings according to the geographic region should be interpreted with caution. Finally, it is important to acknowledge that factors independent from the COVID-19 pandemic could have impacted TAVR procedural volume.

CONCLUSIONS

The COVID-19 pandemic was associated with a considerable reduction in TAVR procedural volume worldwide. This impact was most acute during the first pandemic wave and waned as countries and health care systems adapted to the health crisis. The reduction in TAVR activity was more pronounced in Africa, Central-South America, and Asia, as well as in private hospitals, urban areas, low-volume centers, and countries with lower development and economic status, higher COVID-19 incidence, and more stringent governmental public health responses. This information should inform national public health policy in case of future global health crises.

FUNDING SUPPORT AND AUTHOR DISCLOSURES

Dr Lefèvre has served as a proctor for Edwards Lifesciences; and received minor fees from Boston Scientific, Terumo, and Abbott. Dr Pilgrim has received research, travel, or educational grants to the institution without personal remuneration from Biotronik, Boston Scientific, Edwards Lifesciences, and ATSens; and speaker fees and consultancy fees to the institution from Biotronik, Boston Scientific, Edwards Lifesciences, Abbott, Medtronic, Biosensors, and Highlife. Dr Van Mieghem has received research grant support from Abbott Vascular, Boston Scientific, Edwards Lifesciences, Medtronic, Daiichi Sankyo, AstraZeneca, Teleflex; and advisory board fees from Abbott Vascular, Boston Scientific, Inari, JenaValve, Medtronic, Daiichi Sankyo, AstraZeneca, Siemens, Pie Medical, and Teleflex. Dr Swaans has served as a proctor/lecturer for Abbott Vascular, Boston Scientific, Bioventrix Inc, Cardiac Dimensions, Edwards Lifesciences, GE Healthcare, Medtronic, and Philips Healthcare. Dr Prendergast has received speaker/consultancy fees from Medtronic, MicroPort, Anteris, and Edwards Lifesciences. Dr Resar has received institutional research funding from Medtronic, Edwards Lifesciences, and Abbott; and served as a TAVR proctor for Medtronic. Dr Chen has served as a consultant for Venus MedTech. Dr Hildick-Smith has received research funds and speaker fees from Medtronic. Dr Spence has received TAVR proctoring and consultancy fees from Medtronic, Boston Scientific, and Edwards Lifesciences. Dr Bunc has served as a proctor for Abbott, Meril, Edwards Lifesciences, and Medtronic. Dr Molnár has served as a consultant for Medtronic and Abbott. Dr Toggweiler has served as a consultant and proctor for Medtronic, Boston Scientific, and Biosensors; has served as a proctor for Edwards Lifesciences and Abbott Vascular; has served as a consultant for Medira, Shockwave, Teleflex, atHeart Medical, Cardiac Dimensions, and Polares Medical; has received institutional research grants from Boston Scientific, Fumedica, and Novartis; has received speaker honoraria from Sanofi, AstraZeneca, ReCor Medical, and Daiichi Sankyo; and holds equity in Hi-D Imaging. Dr Ojeda has received consulting fees from Medtronic and Edwards Lifesciences; and speaker fees from Philips and Word Medica. Dr Toutouzas has served as a proctor for Medtronic, Abbott, Myval, and Boston Scientific. Dr AlMerri has served as a TAVR proctor for Medtronic. Dr Noble has served as a proctor for Medtronic; and received institutional grant support from Edwards Lifesciences, Boston Scientific, Abbott Vascular, and Medtronic. Dr Kala has served as a consultant for Boston Scientific; served on the Speakers Bureau for Edwards Lifesciences, Servier, and AstraZeneca; and received research support from Novartis. Dr Kurt has served as a TAVR proctor for Abbott. Dr Yin has served as a TAVR proctor for Medtronic, Edwards Lifesciences, and Abbott. Dr Sztejfman has served as a proctor for Boston Scientific, Edwards Lifesciences, Medtronic, Meril Life Sciences, and MicroPort. Dr Mendiz has served as a proctor for Medtronic, Boston Scientific, and Edwards Lifesciences. Dr Gunasekaran has received fees from Medtronic, Meril Life Sciences, Abbott, and Boston Scientific. Dr Kao has served as a proctor for Medtronic and Edwards Lifesciences. Dr Dager has served as a consultant for Medtronic. Dr Ferrero-Guadagnoli has served as a proctor for Boston Scientific, Edwards Lifesciences, and Medtronic. Dr Modine has served as a consultant for and received honorarium from Abbott, Medtronic, and Edwards Lifesciences. Dr Hayashida has served as a proctor for Edwards Lifesciences, Medtronic, and Abbott. Dr Makkar has received research grants from Abbott, Edwards Lifesciences, and Boston Scientific, and served as a consultant for Cordis and Medtronic. Dr Mylotte has received institutional grant funding from Boston Scientific and Medtronic; and personal fees from Boston Scientific, Medtronic, and MicroPort. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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TABLE 5 Development and Economic Statuses

	Variation in the Average Number of TAVR Cases per Month per Center		
	Rate (95% CI)	**IRR (95% CI)**	***P* Value**
Development status (HDI)[a]			
Prepandemic period	10.46 (8.19-12.72)	NA	NA
First wave	NA	1.02 (1.02-1.03)	<0.001
Second wave	NA	1.00 (1.00-1.01)	0.13
Third wave	NA	1.00 (0.99-1.00)	0.56
Economic status (GDP per capita)[a]			
Prepandemic period	10.46 (8.19-12.72)	NA	NA
First wave	NA	1.05 (1.03-1.07)	<0.001
Second wave	NA	1.02 (1.00-1.04)	0.045
Third wave	NA	1.01 (0.99-1.03)	0.39
Economic status (GNI per capita)[a]			
Prepandemic period	10.46 (8.19-12.72)	NA	NA
First wave	NA	1.05 (1.03-1.07)	<0.001
Second wave	NA	1.01 (1.00-1.03)	0.11
Third wave	NA	1.00 (0.98-1.02)	0.86

[a]IRR for each 1% of HDI (development status) and each $10,000 of GDP/GNI per capita (economic status).
Abbreviations as in Tables 1 and 2.

TABLE 6 COVID-19 Incidence and Governmental Public Health Response

	Variation in the Average Number of TAVR Cases per Month per Center		
	Rate (95% CI)	**IRR (95% CI)**	***P* Value**
COVID-19 incidence (monthly number of COVID-19 cases per thousand inhabitants)[a]			
Prepandemic period	10.46 (8.19-12.72)	NA	NA
First wave	NA	0.92 (0.90-0.94)	<0.001
Second wave	NA	1.00 (0.99-1.00)	0.38
Third wave	NA	1.00 (0.99-1.00)	0.49
Governmental public health response (COVID-19 stringency index)[a]			
Prepandemic period	10.46 (8.19-12.72)	NA	NA
First wave	NA	0.91 (0.89-0.92)	<0.001
Second wave	NA	0.96 (0.94-0.98)	<0.001
Third wave	NA	0.98 (0.96-1.00)	0.018

[a]IRR for each COVID-19 case per thousand inhabitants (COVID-19 incidence), and each 10% of COVID-19 stringency index (governmental public health response).
Abbreviations as in Tables 1 and 2.

PERSPECTIVES

WHAT IS KNOWN? Patients with symptomatic severe aortic valve stenosis necessitating TAVR are especially vulnerable to treatment delays, and treatment deferral is associated with an increased risk of hospitalization and death. Single-center and regional reports have suggested reduced TAVR procedural volume during the COVID-19 pandemic. However, international reports on global TAVR activity are lacking.

WHAT IS NEW? This study reports the impact of the COVID-19 pandemic on global TAVR procedural volume, including centers across the globe. We report that the first and second waves of the COVID-19 pandemic were associated with a significant reduction in global TAVR activity, whereas the third wave did not. The impact of the COVID-19 pandemic on TAVR activity was heterogeneous across countries, and was influenced by socioeconomic and health care system factors, the magnitude of national COVID-19 incidence, and the severity of governmental public health measures introduced in response to the pandemic.

WHAT IS NEXT? The study results should inform World Health Organization and national public health policy in case of future global health crises. Public health messaging should reinforce the importance of maintaining scheduled cardiovascular care and health care systems should be assessed for and developed to become pandemic-resilient.

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APPENDIX For supplemental tables, please see the online version of this paper.