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NEW RESEARCH PAPER

Impact of COVID-19 on Cardiovascular Testing in the United States Versus the Rest of the World

The INCAPS-COVID Study

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ABSTRACT

OBJECTIVES This study sought to quantify and compare the decline in volumes of cardiovascular procedures between the United States and non-US institutions during the early phase of the coronavirus disease-2019 (COVID-19) pandemic.

BACKGROUND The COVID-19 pandemic has disrupted the care of many non-COVID-19 illnesses. Reductions in diagnostic cardiovascular testing around the world have led to concerns over the implications of reduced testing for cardiovascular disease (CVD) morbidity and mortality.

METHODS Data were submitted to the INCAPS-COVID (International Atomic Energy Agency Non-Invasive Cardiology Protocols Study of COVID-19), a multinational registry comprising 909 institutions in 108 countries (including 155 facilities in 40 U.S. states), assessing the impact of the COVID-19 pandemic on volumes of diagnostic cardiovascular procedures. Data were obtained for April 2020 and compared with volumes of baseline procedures from March 2019. We compared laboratory characteristics, practices, and procedure volumes between U.S. and non-U.S. facilities and between U.S. geographic regions and identified factors associated with volume reduction in the United States.

RESULTS Reductions in the volumes of procedures in the United States were similar to those in non-U.S. facilities (68% vs. 63%, respectively; $p = 0.237$), although U.S. facilities reported greater reductions in invasive coronary angiography (69% vs. 53%, respectively; $p < 0.001$). Significantly more U.S. facilities reported increased use of telehealth and patient screening measures than non-U.S. facilities, such as temperature checks, symptom screenings, and COVID-19 testing. Reductions in volumes of procedures differed between U.S. regions, with larger declines observed in the Northeast (76%) and Midwest (74%) than in the South (62%) and West (44%). Prevalence of COVID-19, staff redeployments, outpatient centers, and urban centers were associated with greater reductions in volume in U.S. facilities in a multivariable analysis.

CONCLUSIONS We observed marked reductions in U.S. cardiovascular testing in the early phase of the pandemic and significant variability between U.S. regions. The association between reductions of volumes and COVID-19 prevalence in the United States highlighted the need for proactive efforts to maintain access to cardiovascular testing in areas most affected by outbreaks of COVID-19 infection. (J Am Coll Cardiol Img 2021;■:■-■) © 2021 by the American College of Cardiology Foundation.

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ABBREVIATIONS AND ACRONYMS

CAC = coronary artery calcium scan

CCTA = coronary computed tomographic angiography

CMR = cardiac magnetic resonance

COVID-19 = coronavirus disease-2019

CVD = cardiovascular disease

IAEA = International Atomic Energy Agency

ICA = invasive coronary angiography

PET = positron emission tomography

SPECT = single-photon emission computed tomography

TEE = transesophageal echocardiogram

TTE = transthoracic echocardiogram

The coronavirus disease-2019 (COVID-19) pandemic has led to profound disruptions in the delivery of health care around the world. Clinicians have reduced in-person visits, eliminated elective procedures, and increased reliance on telehealth within a remarkably short period of time (1,2). In addition, data from several countries have confirmed declines in emergency room visits and hospitalizations for a variety of common non-COVID-19 medical and surgical conditions, leading to concerns about an emerging global health crisis from delayed or missed diagnoses during the pandemic (3-7).

Disruptions in medical care are especially concerning for patients with cardiovascular disease (CVD), which is the leading cause of death for men and women globally. Prior to the pandemic, CVD accounted for 17.9 million deaths worldwide annually (8). The timely performance of advanced cardiovascular diagnostic tests is essential to the accurate diagnosis, risk stratification, and management of patients with known or suspected CVD (9-11). However, diagnostic cardiovascular procedures, as with other elective or nonemergent procedures, have been reduced, delayed, or canceled entirely during the pandemic. We recently reported that worldwide volumes of cardiovascular testing declined by 64% during the early phase of the pandemic (12), whereas studies from at least 5 countries reported declines of 30% to 40% in invasive coronary angiography (ICA) procedures for acute coronary syndrome (ACS), causing growing concern over the short- and long-term implications of reductions in diagnostic cardiovascular testing on overall CVD morbidity and mortality around the world (13-18). At the same time, imaging guidance statements amid the pandemic point to evolving indications for cardiovascular testing to now prioritize acute diagnosis, safety, and decreased downstream resource usage (19-21).

Furthermore, in addition to the acute cardiovascular complications caused by COVID-19 (22-25), an increasing body of evidence is showing possible sustained cardiovascular effects related to the disease (22,26). For example, a recent study of patients who recovered from COVID-19 showed that most of those studied had signs consistent with cardiac inflammation (22), highlighting the need for cardiovascular testing to identify a large at-risk population with new, undiagnosed CVD.

The extent to which the early phase of the COVID-19 pandemic has reduced volumes of diagnostic cardiovascular procedures in the United States and the differential impact of the pandemic on U.S. and non-U.S. laboratories, has not been reported. In an effort to comprehensively quantify reductions in

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cardiovascular testing during the early phase of the pandemic, the International Atomic Energy Agency (IAEA, Vienna, Austria) coordinated a worldwide study, called the INCAPS-COVDI (IAEA Non-invasive Cardiology Protocols Study of COVID-19), to characterize volumes of procedures from facilities around the world that perform diagnostic cardiovascular procedures. We recently reported an analysis of the worldwide impact of the COVID-19 pandemic on cardiac diagnostic procedures (12). In this study, we compared volumes of procedure data between U.S. and non-U.S. institutions and between U.S. regions, and we identified factors associated with diagnostic procedure volume reduction in the U.S. during the early months of the COVID-19 pandemic.

METHODS

STUDY DESIGN. The INCAPS-COVID executive committee, comprising experts in cardiac imaging from every world region, was convened to study the impact of the COVID-19 pandemic on worldwide diagnostic cardiovascular procedure volumes. A study was designed in which facilities performing cardiac diagnostic procedures were asked to report the total number and type of noninvasive and invasive procedures performed at their institution during the months of March 2019, March 2020, and April 2020. Regional and national coordinators facilitated outreach to IAEA-registered institutions and through professional organizations to invite participants to participate in the study. U.S. regional coordinators (New England, Mid Atlantic, South East, South, Midwest, South West, and West) helped recruit centers in their respective subregions to increase U.S. representation in the study. Publicizing on social media platforms (Twitter, LinkedIn, Facebook) also helped to ensure broad and diverse participation in the survey. March 2019 data were treated as baseline values when assessing reduction in procedure volume during March and April 2020 (i.e., early months of the pandemic). Data were aggregated by country and by the 8 world regions defined by the IAEA: Africa, Eastern Europe, Far East, Latin America, Middle East, South Asia, North America (i.e., Canada and the United States), South East Asia and the Pacific, and Western Europe (27). In that analysis, we compared data between U.S. and non-U.S. laboratories, as well as between U.S. regions as defined by the U.S. Census Bureau: Midwest, Northeast, South, and West (28). Notwithstanding that Puerto Rico is a U.S. territory (as for other U.S. territories), it is not considered part of the 4 statistical regions defined by the U.S. Census Bureau and was therefore included in the non-U.S. group for the purposes of this analysis. However, the inclusion of Puerto Rico in the non-U.S. group did not increase the number of non-U.S. countries reported in the results, as it is not an individual country. Participation was voluntary and no patient-level or identifiable data were collected and therefore institutional review board review was not required for this study.

DATA COLLECTION. Survey data were collected by using a secure software platform hosted by the IAEA, the International Research Integration System (IRIS) (IAEA, Vienna, Austria). Using a standardized data collection form (Supplemental Appendix), each site provided data for procedure volumes for the following test types: stress electrocardiography (ECG), without subsequent imaging; stress echocardiography; stress single-photon emission computed tomography (SPECT); stress positron emission tomography (PET); stress cardiac magnetic resonance (CMR); coronary artery calcium (CAC) scanning; coronary computed tomographic angiography (CCTA); transthoracic echocardiography (TTE); transesophageal echocardiography (TEE); PET cardiac infection studies (fluorine-18 labeled fluorodeoxyglucose to assess for intracardiac infection); nonstress CMR; and ICA. All study types except for ICA were considered noninvasive testing. Facilities described as inpatient hospital only or inpatient and outpatient hospitals were defined as inpatient facilities, whereas facilities defined as outpatient hospitals only, outpatient imaging centers, or outpatient physician practices were defined as outpatient facilities. Teaching facilities were self-identified by survey respondents. Participants also responded to questions regarding the impact of the pandemic on availability of personal protective equipment, staff redeployments, staff and patient safety policies, operational capacity, increased use of telehealth, and staffing of imaging personnel at their institution. Survey questions marked as "planning" or "implemented" were considered affirmative responses compared to those marked as "no plans," which were considered negative responses. Increased use of telehealth was defined as an affirmative response to survey questions regarding usage of telehealth for patient care (ie, direct contact with patients).

U.S. regional analysis included data compiled from external sources, including COVID-19 prevalence data (29) and U.S. demographic and socioeconomic data from the 2010 U.S. census (30). At the time of this analysis, U.S. county data were the smallest geographic unit of available COVID-19 data; therefore this was the most granular level of census data used in our analyses. County-level COVID-19 and census data were compiled based on county Federal Information Processing System (FIPS) codes (31). FIPS codes were assigned to each facility based on the county in which the facility operates.

STATISTICAL ANALYSIS. Differences in frequency distributions were statistically compared using Pearson chi-squared and Fisher exact tests, and differences in continuous variables were compared using Wilcoxon rank sum and Kruskal-Wallis tests. A robust regression model using Huber's M-estimator to reduce the weight of influential outliers (32) was used to determine factors associated with the percentage of reduction in procedure volume in the United States between March 2019 and April 2020. Variables with a p value $\leq$0.25 in univariate analyses were considered in the multivariable model, with final inclusion based on stepwise elimination of variables exceeding the significance level of 0.10. Variables considered in the multivariable model included county COVID-19 prevalence (cases per 10,000 residents) on April 30, 2020 (29); outpatient facility; redeployments; use of telehealth for patient care; urban center (defined as a facility located in a county in a metro area with population >1 million, based on U.S. Department of Agriculture 2013 Rural-Urban Continuum Codes) (33) political party affiliation of the current state governor; political party affiliation of the state electoral college vote in the 2016 presidential election; and county-level census demographics (30), including household income, and percentage of the county population that was foreign-born, black, and unemployed. A 2-tailed p value $<$ 0.05 was considered statistically significant. Statistical analysis was conducted using Stata/SE version 15.1 software (StataCorp, College Station, Texas). The authors had full access to and took full responsibility for the integrity of the data.

RESULTS

A total of 936 questionnaires were submitted, of which 27 duplicates were excluded from the analysis. Worldwide data were analyzed from a final sample of 909 facilities in 108 countries, including U.S. data from 155 facilities located in 107 distinct counties in 40 U.S. states. Counties included in this analysis encompassed approximately 31% of the entire U.S. population. Volumes of procedure data were submitted from 138 U.S. centers totaling 329,472 studies (170,463 in March 2019; 104,019 in March 2020; and 54,990 in April 2020) and 708 non-U.S. centers totaling 988,227 studies (508,175 in March 2019; 290,606 in March 2020; and 189,446 in April 2020) for a combined 1.3 million imaging studies.

FACILITY CHARACTERISTICS. Characteristics of U.S. and non-U.S. imaging centers are summarized in **Table 1**. Compared to non-U.S. centers, a greater percentage of U.S. centers performed nearly every type of imaging test except for CCTA and CMR. PET cardiac infection was the only test used less frequently in U.S. laboratories than in non-U.S. laboratories (9% vs. 17%, respectively; p = 0.018). U.S. institutions also reported a greater number of procedures per center than non-U.S. centers (641 vs. 215, respectively; p $<$ 0.001) and more outpatient studies (30% vs. 16%, respectively; p $<$ 0.001), and a greater percentage of imaging staff were redeployed to nonimaging-related activities during the pandemic than non-U.S. centers (29% vs. 19%, respectively; p = 0.001). The number of hospital beds and percentage of teaching institutions were not significantly different between U.S. and non-U.S. centers. U.S. regional participation was greatest in the South (57 facilities), followed by the Northeast (43 facilities), the Midwest (28 facilities), and the West (27 facilities). The proportion of centers performing each imaging test was similar between U.S. regions, with significant differences observed only with stress ECG. Characteristics including median procedures per facility, number of hospital beds, proportion of teaching institutions, and redeployment of medical staff were similar among U.S. regions, although the proportion of inpatient and outpatient facilities was statistically different. Cardiologists submitted more surveys from U.S. facilities than non-U.S. facilities (70% vs. 31%, respectively), whereas nuclear medicine physicians submitted more surveys from non-U.S. facilities (3% vs. 42%, respectively) (Supplemental Table 1).

PROCEDURE VOLUMES FOR U.S. VERSUS NON-U.S. CENTERS. Percentage of reductions in cardiovascular procedure volumes are summarized for U.S. and non-U.S. centers from March 2019 to April 2020 (**Table 2, Figure 1** and Supplemental Table 2). Total reductions in procedure volumes during the early pandemic in U.S. facilities were similar to those in non-U.S. facilities (68% vs. 63%, respectively; p = 0.237) (**Figure 1**). U.S. facilities saw greater reductions in ICA (69% vs. 53%, respectively; p $<$ 0.001) and stress PET procedures (58% vs. 51%, respectively; p = 0.020) than non-U.S. facilities. The declines in all noninvasive studies were similar between U.S. and non-U.S. facilities (68% vs. 64%, respectively; p = 0.118). Reductions were also similar between U.S. and non-U.S. facilities regardless of facility type, teaching status, redeployment of medical staff, layoffs, or increased use of technologies such as telehealth services. For both U.S. and non-U.S. facilities, declines in aerosol-

TABLE 1 Characteristics for U.S., Non-U.S., and U.S. Regional Institutions That Perform Diagnostic Cardiovascular Testing Procedures

	U.S. Regions					Worldwide		
	Midwest	Northeast	South	West	p Value	U.S.	Non-U.S.	p Value
Number of states/countries*	10	7	16	7		40	107*	
Number of centers, total	28	43	57	27		155	754	
With procedure volume data	25	41	49	23		138	708	
Type of test†								
Stress ECG	14 (56)	36 (88)	35 (71)	14 (61)	0.023	99 (72)	302 (43)	<0.001
Stress Echocardiography	18 (72)	28 (68)	26 (53)	14 (61)	0.192	86 (62)	202 (29)	<0.001
Stress SPECT	22 (88)	37 (90)	48 (98)	20 (87)	0.114	127 (92)	513 (72)	<0.001
Stress PET	6 (24)	9 (22)	13 (27)	7 (30)	0.891	35 (25)	53 (7)	<0.001
Stress CMR	11 (44)	11 (27)	11 (22)	4 (17)	0.176	37 (27)	130 (18)	0.023
CT coronary calcium	16 (64)	20 (49)	20 (41)	13 (57)	0.175	69 (50)	221 (31)	<0.001
CT coronary angiography	17 (68)	23 (56)	27 (55)	15 (65)	0.527	82 (59)	397 (56)	0.468
TTE	17 (68)	28 (68)	30 (61)	16 (70)	0.801	91 (66)	248 (35)	<0.001
TEE	17 (68)	20 (49)	21 (43)	14 (61)	0.111	72 (52)	208 (29)	<0.001
PET cardiac infection	2 (8)	5 (12)	3 (6)	2 (9)	0.793	12 (9)	118 (17)	0.018
CMR	15 (60)	21 (51)	17 (35)	14 (61)	0.086	67 (49)	292 (41)	0.112
All noninvasive testing	25 (100)	41 (100)	49 (100)	23 (100)	1.000	138 (100)	708 (100)	1.000
Invasive angiography	13 (52)	17 (41)	26 (53)	12 (52)	0.625	68 (49)	216 (31)	<0.001
Baseline procedures per center‡	1,290 (350-2,250)	686 (280- 1,832)	505 [240- 1,052)	470 (195- 1,465)	0.097	641 (242- 1,709)	215 (68- 768)	<0.001
Hospital beds	500 (400- 686)	693 (350- 867)	400 (182- 745)	450 (150- 600)	0.196	522 (250- 793)	504 (230- 900)	0.449
Type of center								
Inpatient	26 (93)	28 (65)	37 (65)	18 (67)	0.023	108 (70)	631 (84)	<0.001
Outpatient	2 (7)	15 (35)	20 (35)	9 (33)		47 (30)	123 (16)	
Teaching institution	21 (78)	28 (65)	34 (60)	15 (54)	0.436	98 (63)	499 (66)	0.480
Imaging staff redeployed	4 (15)	14 (33)	22 (39)	5 (18)	0.068	45 (29)	141 (19)	0.004

Values are n (%) or median (interquartile range). *Reflects the number of non-U.S. countries rather than U.S. states. Data from Puerto Rico are included in the non-U.S. category but do not increase the count of 107 non-U.S. countries. †Percentages displayed in parentheses refer to the percentage of centers that reported procedure volume data for each specific test (n = number of centers reporting procedure volume data). ‡March 2019 procedure volumes were the baseline for each facility.

CMR = cardiac magnetic resonance; ECG = electrocardiogram; echo = echocardiogram; PET = positron emission tomography; SPECT = single-photon emission computed tomography; TEE = transesophageal echocardiogram; TTE = transthoracic echocardiogram.

generating procedures that typically require exercise-induced stress, such as stress ECG and stress echocardiography, were greater than declines in stress SPECT and stress PET, which can be performed preferentially by using pharmacological stress agents. Survey responses showed that most U.S. (71%) and non-U.S. (64%) facilities were planning or had already adopted policies to avoid exercise stress testing in favor of pharmacologic testing (Supplemental Table 3). A smaller but still significant number of U.S. (40%) and non-U.S. (43%) facilities also used modified nuclear stress protocols to prioritize shorter acquisition times and stress-first protocols when possible.

PROCEDURE VOLUMES FOR U.S. REGIONAL CENTERS. Table 2 summarizes the percentage of decline in volumes of cardiovascular procedures among U.S. regions. Total reductions in volumes among U.S. regions during the early months of the pandemic were similar from March 2019 to March 2020 ($p = 0.069$) but different from March 2019 to April 2020 ($p < 0.001$). The largest declines were observed in the Northeast (76%) and Midwest (74%) facilities, followed by facilities in the South (62%) and West (44%) (Central Illustration). Reductions in volumes differed significantly among U.S. regions for 6 of 12 diagnostic tests, including stress ECG, stress echo, stress SPECT, CCTA, TTE, and ICA. Declines were highest in the Northeast and Midwest and lowest in the South and West for every test type except for CCTA and CMR (Figure 2). Reductions in volumes of procedures varied significantly among U.S. regions for every facility characteristic, except among facilities that reported no changes in telehealth usage. Reductions for each facility characteristic were greater for the Northeast and Midwest than for the South and West regions.

OPERATIONAL CAPACITY, SAFETY POLICIES, AND STAFFING. Major differences were noted in the responses for operational capacity, safety policies, and staffing between U.S. and non-U.S. facilities (Table 3). For example, compared to non-U.S. centers, a greater proportion of U.S. centers reported increased usage of telehealth for direct patient care (90% vs. 65%,

TABLE 2 Reduction in Cardiac Imaging Volume by Diagnostic Test and Facility Characteristics

	U.S. Regions					Worldwide		
	Midwest	Northeast	South	West	p Value†	U.S.	Non-U.S.	p Value†
Reduction in total procedures								
March 2019–March 2020	41	44	29	48	0.069	39	43	0.803
March 2020–April 2020	56	58	47	−7	<0.001	47	35	0.470
March 2019–April 2020	74	76	62	44	<0.001	68	63	0.237
By diagnostic test*								
Stress ECG	85	91	81	61	0.050	85	84	0.426
Stress echocardiography	82	90	73	67	0.038	81	83	0.551
Stress SPECT	77	87	69	47	<0.001	75	74	0.062
Stress PET	78	77	65	30	0.143	58	51	0.021
Stress CMR	78	97	62	58	0.642	84	69	0.786
CT coronary calcium	97	95	93	83	0.743	94	60	0.366
CT coronary angiography	60	82	72	48	0.045	71	52	0.753
TTE	68	69	54	36	0.037	61	58	0.492
TEE	86	83	69	71	0.057	80	73	0.114
PET cardiac infection	0	88	78	42	0.186	80	58	0.957
CMR	75	78	73	50	0.111	72	62	0.422
All noninvasive testing	74	76	62	44	<0.001	68	64	0.118
Invasive coronary angiography	77	75	63	41	0.013	69	53	<0.001
By facility characteristic*								
Type of facility								
Inpatient	74	76	63	45	<0.001	69	60	0.176
Outpatient	54	87	54	40	0.043	59	78	0.674
Teaching status								
Teaching	74	75	61	46	0.002	68	60	0.187
Nonteaching	74	83	65	39	0.038	66	72	0.874
Redeployment during pandemic								
Redeployed	86	84	72	42	0.003	76	62	0.810
Not redeployed	71	74	54	44	0.012	65	63	0.045
Changes in staffing								
Furloughed or laid off staff	75	81	58	48	0.049	69	75	0.020
No changes	73	74	65	42	0.004	67	60	0.932
Telehealth services for patient care								
Increased use	75	76	64	44	<0.001	69	64	0.135
No change in use	43	77	43	-	0.108	46	58	0.470

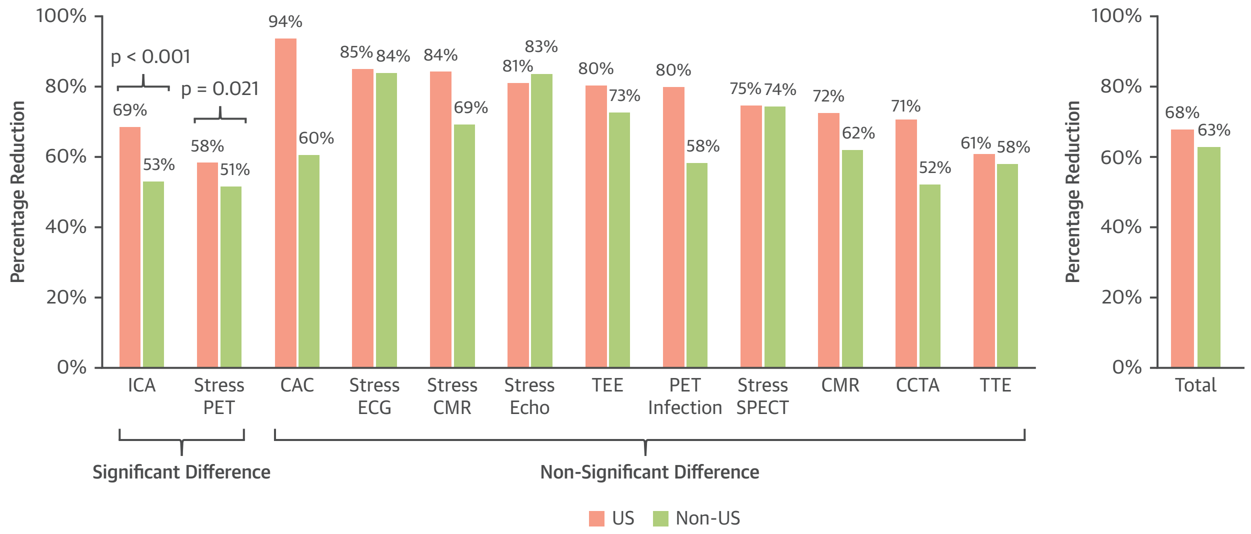
Values are %, unless otherwise indicated. *Percentage reductions were calculated as the cumulative reduction of all procedures in each category from March 2019 to April 2020. †The p values were calculated by comparing the distributions of percentage reductions of individual laboratories for each category.

CMR = cardiac magnetic resonance imaging; ECG = electrocardiogram; echo = echocardiogram; PET = positron emission tomography; SPECT = single-photon emission computed tomography; TEE = transesophageal echocardiogram; TTE = transthoracic echocardiogram; U.S. = United States.

respectively; $p < 0.001$) and use of patient screening measures, such as temperature checks (87% vs. 77%, respectively; $p = 0.008$), symptom screening (97% vs. 86%, respectively; $p < 0.001$), and COVID-19 testing (46% vs. 26%, respectively; $p < 0.001$). U.S. facilities were also more likely to require the use of face masks than non-U.S. facilities (97% vs. 81%, respectively; $p < 0.001$). Furloughs of nonphysician imaging staff were reported in more U.S. centers than in non-U.S. centers (35% vs. 22%, respectively; $p = 0.001$), whereas furloughs of physicians were reported in fewer U.S. centers than in non-U.S. centers (13% vs. 21%, respectively; $p = 0.025$). Survey responses were mostly similar among U.S. regions, with slight differences in reports of increased time to clean and disinfect equipment, and nonphysician layoffs, which were notably higher in the South than in other regions.

FACTORS ASSOCIATED WITH PROCEDURE VOLUME REDUCTION IN THE U.S. Results of a linear regression analysis are presented in Table 4. In a multivariable analysis, the mean reduction in volumes of procedures during the early phase of the COVID-19 pandemic was 11.5% greater for facilities reporting staff redeployments than those reporting no redeployments (95% confidence interval [CI]: 5.3% to 17.7%; $p < 0.001$), 12.5% greater for outpatient facilities than for inpatient facilities (95% CI: 6.3% to 18.7%;

FIGURE 1 Percentage Reduction in Procedure Volumes from March 2019 to April 2020 for U.S. and Non-U.S. Imaging Centers



Clustered bar graphs showing the percentage reduction in procedure volumes from March 2019 to April 2020 by diagnostic test type and by U.S. **(red)** and non-U.S. **(green)** centers. ICA ($p < 0.001$) and stress PET ($p = 0.021$) were the only tests in which the difference in percent reduction between U.S. and non-U.S. centers was statistically significant. CAC = coronary artery calcium scan; CCTA = coronary computed tomographic angiography; CMR = cardiac magnetic resonance imaging; ECG = electrocardiogram; echo = echocardiogram; ICA = invasive coronary angiography; IQR = interquartile range; PET = positron emission tomography; SPECT = single-photon emission computed tomography; TEE = transesophageal echocardiogram; TTE = transthoracic echocardiogram.

$p < 0.001$), 9.7% greater for urban centers than for nonurban centers (95% CI: 3.3% to 16.1%; $p = 0.003$), and 0.6% greater for every 1 case increase per 10,000 residents in the county COVID-19 prevalence (95% CI: 0.1% to 1.1%; $p = 0.011$). The remaining variables described in the methods, including increased usage of telehealth, political factors, and U.S. census demographic characteristics, were not found to be associated with volume reduction in a multivariable analysis.

DISCUSSION

This report examined worldwide data from 909 institutions in 108 countries to investigate how the COVID-19 pandemic has impacted the volume of diagnostic cardiovascular procedures performed in the U.S. and non-U.S. facilities and to determine factors associated with volume reduction in U.S. facilities. We found that volume reductions were generally similar between U.S. and non-U.S. facilities for all diagnostic procedures apart from ICA, in which the U.S. experienced greater declines (69% vs. 53%, respectively; $p < 0.001$). Conversely, we observed significant differences between U.S. regions, with the greatest declines seen in the Northeast and Midwest for nearly every type of cardiovascular test. Factors statistically correlated with greater reduction in volumes in a multivariable analysis included COVID-19 prevalence, staff redeployments, outpatient centers, and urban centers.

The impact of the pandemic on worldwide CVD morbidity and mortality is an area of growing concern. Already, multiple reports have described worrisome declines in the rates of percutaneous revascularization procedures for ACS. Garcia et al. (18) evaluated 9 high-volume cardiac catheterization facilities in the United States and found that laboratory activations for ST-segment elevation myocardial infarctions (STEMI) declined from baseline values by 38% at the end of March 2020. This decrease was similar to reductions in STEMI activations reported in separate studies from Spain (40%) (16) and Italy (33%) (15). One possible explanation could be increased usage of noninvasive management pathways for ACS. However, studies have shown that, in fact, overall hospitalizations for ACS have also declined by a similar percentage (13,14). Mafham et al. (13) evaluated hospital admission data in England and found that admissions for ACS in March 2020 had declined by 40% (13). Our data also showed reductions in ICA volumes of 40% in U.S. facilities and 43% in non-U.S. facilities at the end of March 2020, similar to those in previous studies. However, in April 2020, we

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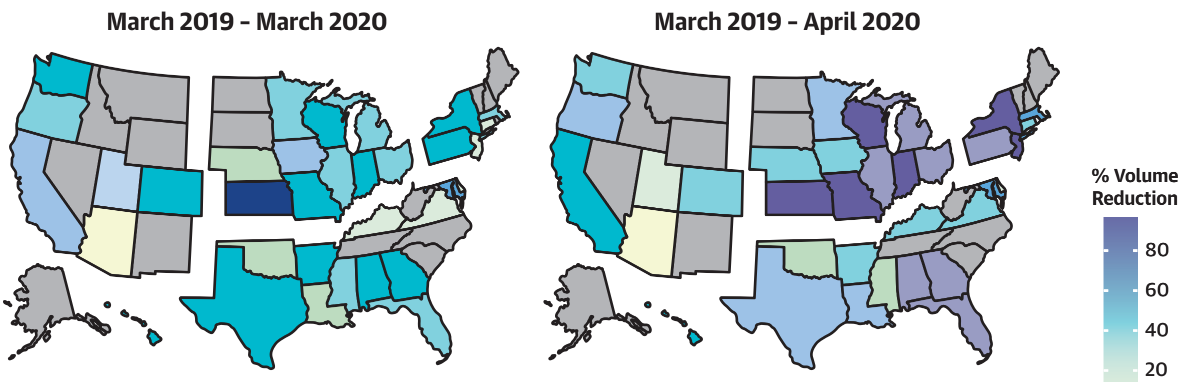
CENTRAL ILLUSTRATION **Geographic Differences in Diagnostic Cardiovascular Procedure Volume Reductions in the United States**



Hirschfeld, C.B. et al. J Am Coll Cardiol Img. 2021;■(■):■-■.

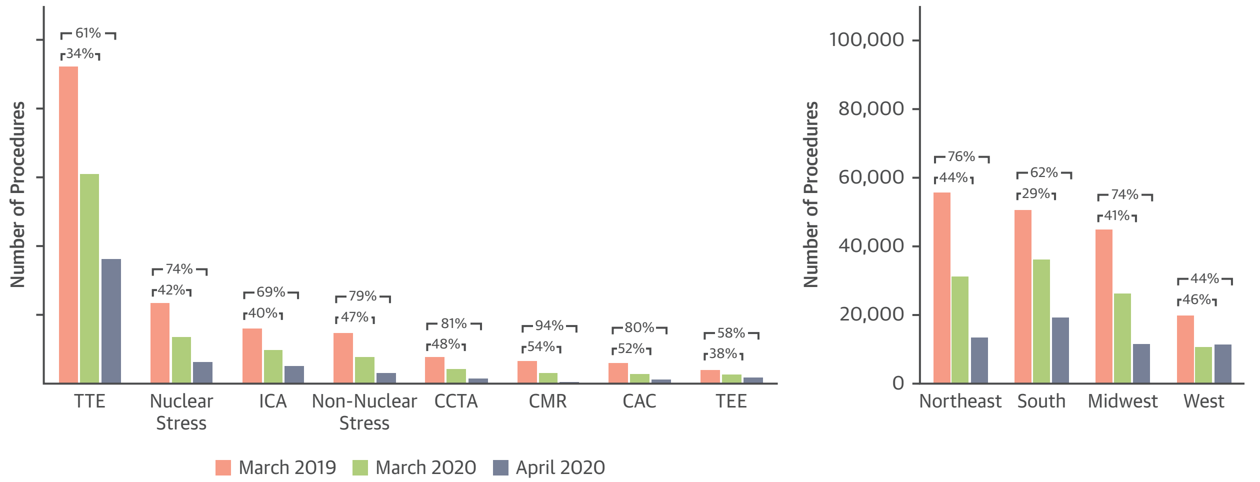
U.S. maps demonstrate the percentage of reduction in diagnostic cardiovascular procedures from March 2019 to March 2020 **(left map)** and March 2019 to April 2020 **(right map)**. States are grouped together by U.S. census regions: West **(left)**, Midwest **(top middle)**, Northeast **(top right)**, and South **(bottom right)**. Alaska and Hawaii are included in the West region. Differences in overall volume reductions were similar between U.S. regions in March 2020 ($p = 0.069$) but different in April 2020 ($p < 0.001$), with the greatest declines seen in the Northeast and Midwest.

observed even greater worldwide declines in ICA procedures, with a significantly greater reduction in U.S. centers than in non-U.S. centers (69% vs. 53%, respectively; $p < 0.001$).

The greater reduction of ICA procedures in U.S. facilities could relate to several factors, including the rapid rise in COVID-19 cases in the U.S. during March and April of 2020. New York City was widely considered to be one of the epicenters of the COVID-19 pandemic in April (34). Thus, it is not surprising that our data also revealed significant differences in volume reductions between U.S. regions, with a nearly 2-fold greater decline in ICA procedures in the Northeast than in the West (77% vs. 41%, respectively; $p < 0.001$). These declines are unlikely due to a true decrease in the incidence of ACS. In fact, Kwong et al. (35) showed that the risk of acute myocardial infarction was approximately 3 to 6 times higher in the first 7 days of viral respiratory infection. A more alarming, and more likely, alternative is the decline in emergency room visits for chest pain due to the reluctance of patients to seek medical attention during the pandemic. A recent report from the Centers for Disease Control and Prevention showed that, during the early phase of the pandemic, emergency room visits for chest pain decreased by 24,258 visits per week across the United States compared to the same period in 2019, whereas visits for acute myocardial infarction declined by 1,156 per week, suggesting that delayed care in these cases might have resulted in "additional mortality" (36). Similar declines in emergency room presentations have been described for acute stroke (37,38), acute surgical complaints (4,39), and even emergency mental health services (40), which are largely believed to be the result of decreased usage of health care services generally during the pandemic, rather than the decreased incidence of non-COVID-19 illnesses. Although the reported declines in hospital presentations and procedures for ACS are a major cause for concern, additional data are urgently needed to better establish the direct impact of these findings on the morbidity and mortality of CVD around the world.

In addition to reductions in ICA procedures, we found that rates of noninvasive cardiovascular procedures also fell sharply during the early pandemic. It is possible that declines in worldwide cardiovascular testing might have curtailed transmission of COVID-19 while permitting an increase in hospital capacity and a decrease in inappropriate testing (41). However, it may also signify a potential looming global health crisis from the millions of CVD diagnoses that could be missed during the pandemic. Overall, declines in noninvasive cardiovascular procedure volumes were similar for U.S. and non-U.S. laboratories (68% vs. 64% reported declines; $p = 0.118$), which is more likely explained by offsetting procedure volume reductions in non-U.S. regions than a true resemblance between U.S. and non-U.S. centers. For example, our international report showed that regions beyond the

FIGURE 2 Reduction in U.S. Cardiovascular Procedure Volumes by Diagnostic Test and Region



Clustered bar graphs display the number of procedures for March 2019 **(red)**, March 2020 **(green)**, and April 2020 **(blue)** for each test and each U.S. region. TTE was the most represented diagnostic test in the study, followed by stress tests and ICA procedures. The greatest declines in the volume of procedures were seen in stress tests, CCTA, CMR, and CAC. Regional declines were greatest in the Northeast and Midwest, followed by the South and West. PET infection is not shown in the figure due to the small sample size. Abbreviations as in Figure 1.

peak of transmission in April 2020 (e.g., Far East and South East Asia) reported the lowest reductions in volume of procedures, whereas regions at the peak or in the early stages of community transmission during the same time period (e.g., Europe and South America, respectively) reported greater reductions in volumes (12).

Variable rates of reductions in procedure volumes for each modality also suggests that factors other than restricted access during the pandemic likely impacted the relative reductions observed. For example, declines in TEE volumes were generally greater than other modalities, likely due to fears of aerosolization with endotracheal intubation. We also found that most U.S. and non-U.S. facilities implemented policies to avoid aerosol-generating exercise stress tests in favor of pharmacologic stress tests while optimizing protocols to shorten patient-staff contact time (e.g., reduced acquisition times and use of stress-first protocols). Consequently, both U.S. and non-U.S. facilities reported greater reductions in stress ECG and stress echocardiography than nuclear stress tests, where image acquisition can be performed at a distance by using pharmacologic stress agents. Reductions in CCTA were also lower than exercise stress tests, raising the possibility that facilities could have used alternative nonstress modalities to diagnose CAD.

In contrast, there were significant differences in reductions of procedure volumes reported among U.S. regions, with greater declines generally observed in the Northeast and Midwest. This difference did not emerge until April 2020 when declines in procedure volumes in the Northeast and Midwest outpaced declines in the South and West. We found that facilities operating in counties with a greater prevalence of COVID-19 in April of 2020 reported greater reductions in cardiovascular testing ($p = 0.011$). This was likely due to the mounting effects of the pandemic in these areas, which led to the abrupt cessation of elective procedures and the suspension of many outpatient medical practices (42,43). Consequently, our analysis revealed that classification as an outpatient practice was also associated with a 12.5% greater reduction in volumes of diagnostic procedures ($p < 0.001$). A common practice in the most affected areas of the pandemic has been to redeploy medical staff to accommodate surges in the number of hospitalized patients (44). In our study, redeployment of imaging staff was associated with an 11.5% greater overall procedure volume reduction, independent of the COVID-19 prevalence in the surrounding area ($p < 0.001$). However, whether redeployments were the direct cause of procedure volume reductions or a consequence of reductions during the early pandemic (e.g., redeployments to reduce overhead) is unknown. Although health care systems must prioritize provision of resources to maintain flexibility and scalability during the pandemic, further examination of the potential adverse consequences of such

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TABLE 3 Changes in Institutional Capacity, Practices, and Staffing That Were Implemented in March 2020 and April 2020 During the COVID-19 Pandemic

	U.S. Regions					Worldwide		
	Midwest (n = 28)	Northeast (n = 43)	South (n = 57)	West (n = 27)	p Value	U.S. (n = 155)	Non-U.S. (n = 754)	p Value
Change in capacity								
Some outpatient activities cancelled	27 (96)	42 (98)	50 (88)	26 (96)	0.217	145 (94)	678 (91)	0.246
All outpatient activities cancelled	15 (54)	27 (66)	31 (54)	16 (59)	0.662	89 (58)	432 (58)	0.991
Phased re-opening after peak pandemic	26 (93)	42 (98)	53 (93)	26 (96)	0.759	147 (95)	663 (89)	0.027*
Extended hours	13 (46)	20 (47)	25 (44)	9 (33)	0.707	67 (43)	321 (43)	0.943
New weekend hours	8 (29)	17 (40)	15 (27)	8 (30)	0.568	48 (31)	227 (31)	0.872
Increased use of telehealth for patient care	26 (93)	38 (88)	51 (89)	24 (92)	0.945	139 (90)	481 (65)	<0.001*
Increased time per study for cleaning/disinfection	21 (75)	42 (98)	48 (84)	21 (78)	0.014*	132 (85)	643 (86)	0.824
Eliminate protocols requiring close contact	23 (82)	36 (84)	42 (75)	24 (89)	0.498	125 (81)	570 (76)	0.191
Change in practice								
Physical distancing	28 (100)	43 (100)	55 (98)	25 (93)	0.150	151 (98)	720 (96)	0.294
Separate spaces for patients with COVID-19	25 (93)	31 (74)	49 (89)	23 (92)	0.098	128 (86)	685 (92)	0.016*
Reduced waiting room time	26 (93)	39 (93)	50 (89)	26 (96)	0.849	141 (92)	687 (92)	0.897
Limit visitors	28 (100)	43 (100)	54 (96)	27 (100)	0.663	152 (99)	731 (98)	0.469
Temperature checks	24 (89)	37 (86)	50 (89)	22 (81)	0.770	133 (87)	579 (77)	0.008*
Symptom screening	28 (100)	42 (98)	51 (94)	27 (100)	0.523	148 (97)	640 (86)	<0.001*
COVID-19 testing	14 (50)	21 (49)	23 (40)	13 (48)	0.777	71 (46)	194 (26)	<0.001*
Require masks	27 (96)	43 (100)	54 (95)	26 (96)	0.478	150 (97)	606 (81)	<0.001*
Change in staffing								
Furlough non-physician imaging staff	13 (50)	10 (26)	19 (34)	10 (36)	0.176	52 (35)	162 (22)	0.001*
Furlough imaging physicians	1 (4)	5 (13)	8 (14)	5 (18)	0.404	19 (13)	152 (21)	0.025*
Reduce salaries of non-physician imaging staff	9 (35)	7 (17)	15 (26)	8 (29)	0.330	39 (26)	185 (25)	0.810
Reduce salaries of imaging physicians	12 (48)	10 (24)	17 (30)	9 (32)	0.278	48 (32)	188 (25)	0.101
Laid off non-physician imaging staff	3 (11)	2 (5)	12 (21)	1 (4)	0.049*	18 (12)	65 (9)	0.229
Laid off imaging physicians	0 (0)	3 (7)	2 (4)	2 (7)	0.487	7 (5)	39 (5)	0.739

Values are n (%). Figures reflect the proportion of laboratories with planned or implemented changes. *Indicates significant p values.
U.S. = United States.

strategies (i.e., decreased availability of essential health care services) and the development of approaches to mitigate them in the future are warranted. Additionally, despite the divisive politicization surrounding the U.S. response to the COVID-19 pandemic (45) factors associated with U.S. political alignment (i.e., the political party affiliation of the current governor and whether the state electoral college voted for the Republican or Democratic nominee in the 2016 presidential election) were also not significantly associated with procedure volume reduction in a multivariable analysis.

Finally, population density has been shown in some studies to be an important factor in both the incidence and death rates resulting from COVID-19 infection (46-48). We found that facilities located in urban counties with a metropolitan population of greater than 1 million had 9.7% fewer procedures than facilities in more rural counties ($p = 0.003$). Although the reason for this is not entirely apparent, it could signify the existence of disparities in access to cardiovascular testing during the pandemic. Major health inequities related to COVID-19 have already been described, with black populations experiencing greater rates of infection, hospitalizations, and even deaths in some studies (49-51). At baseline, black patients in the United States have disproportionately higher morbidity and mortality from CVD and are less likely to receive the same standards of cardiovascular care as nonminority patients (52). Minority populations are also overrepresented in urban communities (53), raising the possibility that minority groups could be more affected by the greater declines in diagnostic cardiac procedures seen in more densely populated counties. Variables accounting for racial and economic differences were not significant in our analysis; however, this study was not designed to detect discrepancies in these characteristics (e.g., county-level data do not fully reflect the demographic characteristics of the neighborhood served by an individual institution, and study participants did not provide patient demographic data associated with their procedure volumes). Nonetheless, communities and individual laboratories should be aware of possible disparities in access to cardiovascular testing that affect the communities most in need of these essential services during the COVID-19 pandemic.

This study has several limitations. First, U.S. regional participation in the INCAPS-COVID study was variable, and data collection is prone to potential biases (e.g., volunteer bias or sampling bias). Thus, the extent to which regional data are representative of the true regional changes in cardiovascular testing is unknown. Additionally, facilities that participated in the survey may not represent the exact distribution of facilities that perform diagnostic cardiac imaging in the community (e.g., only 35% of non-U.S. facilities reported procedure volume data for TTE, a commonly used imaging modality), and the specialty of the survey respondent may have affected the mixture of procedures reported (e.g., nuclear medicine physicians may only report nuclear procedures rather than procedures for the entire department or practice). Nevertheless, the INCAPS-COVID registry constitutes a diverse group of diagnostic facilities representing a broad range of clinical practice settings in each world region. Furthermore, our regression analysis was limited by the granularity of U.S. COVID-19 data, which at the time of this writing, were available only at the county level in most U.S. states. Ideally, a smaller geographical unit of measurement (e.g., census tract) would better reflect the demographic characteristics of the community served by each individual U.S. imaging center. Still, county-level data were sufficient to account for a great degree of variability in our model and enabled us to identify variables significantly associated with U.S. procedure volume reduction. Finally, our results reflect only the early phase of the COVID-19 pandemic. Since the collection of INCAPS-COVID data, institutional and governmental strategies related to the delivery of health care have likely changed, and shifts in diagnostic cardiac testing during the second and third waves of the pandemic remains unknown. In view of this, the INCAPS-COVID Investigators Group is planning to reconvene for additional data collection in early 2021, which is expected to provide additional insights into ongoing changes in worldwide diagnostic cardiovascular testing throughout the COVID-19 pandemic.

CONCLUSIONS

In this study, we observed marked reductions in worldwide cardiovascular testing during the early phase of the COVID-19 pandemic that were generally similar between U.S. and non-U.S. facilities. The major exception was a greater decline in ICA procedures in the U.S. that could be linked to the outbreak of COVID-19 in the United States during this time. Conversely, we observed variations between U.S. regions, with the greatest reductions in procedure volumes seen in the Northeast and Midwest. We found that COVID-19 prevalence, staff redeployments, outpatient centers, and urban centers were all associated with greater declines in total cardiovascular procedure volumes in the United States. The substantial reduction in cardiovascular testing during the early phase of the pandemic highlights the need for strategies to maintain access to this essential resource in areas most affected by COVID-19 outbreaks and to mitigate the predicted burden of CVD morbidity and mortality in the wake of the pandemic.

TABLE 4 Factors Associated with Reduction of Diagnostic Cardiovascular Procedure Volumes during the Early Phase of the COVID-19 Pandemic in a Multivariable Analysis

	Mean Volume Change*	95% CI		p Value
		Lower	Upper	
COVID-19 prevalence	0.6	0.1	1.1	0.011
Staff redeployments	11.5	5.3	17.7	<0.001
Outpatient center	12.5	6.3	18.7	<0.001
Urban center	9.7	3.3	16.1	0.003

Values are %. *Percentage change that can be expected in the mean volume reduction for each variable. For example, mean volume reduction is 11.5% greater in facilities that reported staff redeployments and 12.5% higher in outpatient centers. For the COVID-19 prevalence (continuous variable), every increase in 1 case per 10,000 county residents is expected to increase the mean volume reduction of a facility by an additional 0.6%.

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Nuclear e Imagen Molecular, Society of Cardiovascular Computed Tomography, and Thailand Society of Nuclear Medicine. The authors also thank Olga Morozova for assistance with graphics.

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: INCAPS-COVID is the first study to quantify the marked declines in cardiovascular testing around the world during the early phase of the COVID-19 pandemic. Reduction in volumes of procedures in the United States were similar to those in non-U.S. institutions but differed significantly among U.S. regions, with the greatest declines associated with COVID-19 prevalence, staff redeployments, urban centers, and outpatient centers.

TRANSLATIONAL OUTLOOK: The substantial reduction in diagnostic cardiovascular procedures during the early phase of the COVID-19 pandemic highlights the need to identify strategies to maintain access to cardiac testing in areas most affected by COVID-19 outbreaks in order to mitigate the predicted burden of CVD morbidity and mortality in the wake of the pandemic. Further studies are needed to correlate reductions in cardiovascular testing to clinical outcomes.

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APPENDIX For a list of the INCAPS COVID investigators group and country participation as well as supplemental tables, please see the online version of this paper.