**Disparities in Non-invasive Traditional and Advanced Testing for Coronary Artery Disease: Findings from the INCAPS-COVID 2 Study**

Todd C. Villines, MDa, Patricia Rodriguez-Lozano, MDa\*, Indika Mallawaarachchi, MSa, Michelle C. Williams, MBChB, PhDb, Cole Hirschfeld, MDc, Nathan Better MB, BSd, Leslee J. Shaw, PhDe, Joao V. Vitola, MDf, Rodrigo J. Cerci, MDf, Sharmila Dorbala, MD, MPHg, Chiara Bucciarelli-Ducci MD, PhDh, Ganesan Karthikeyan, MD, MBBS, DM, MSci, Yosef A. Cohen, MDj, Eli Malkovskiy, BAk,l, Michael J. Randazzo, MDm, Andrew D. Choi, MDn, Thomas N. B. Pascual, MD, MSc, MHPEdo, Yaroslav Pynda, MScp, Maurizio Dondi, MD, PhDp, Diana Paez, MD, Medp, Andrew J. Einstein, MD, PhDk,l,q, on behalf of the INCAPS-COVID 2 Investigators Group

aUniversity of Virginia Health System, Charlottesville, VA, USA

bCentre for Cardiovascular Science, University of Edinburgh, Edinburgh, UK

c Division of Cardiology, Weill Cornell Medicine and NewYork-Presbyterian Hospital, New York, NY, USA

dDepartment of Cardiology and Nuclear Medicine, Cabrini Health, Royal Melbourne Hospital, University of Melbourne, Australia

eBlavatnik Family Women’s Health Research Institute, Mount Sinai Medical Center, New York, NY, USA

fQuanta Diagnóstico, Brazil

gBrigham and Women’s Hospital, Boston, MA, USA

hRoyal Brompton and Harefield Hospitals, Guys’ and St Thomas NHS Trust and King’s College London, London, United Kingdom

iDepartment of Cardiology, All India Institute of Medical Sciences, New Delhi, India

jDepartment of Epidimiology, Columbia-Mailman School of Public Health, New York, NY, USA

kSeymour, Paul and Gloria Milstein Division of Cardiology, Department of Medicine, Columbia University Irving MedicalCenter and NewYork-Presbyterian Hospital, New York, NY, USA

lDepartment of Medicine, Columbia University Irving Medical Center and New York-Presbyterian Hospital, New York, NY, USA

mSection of Cardiology, University of Chicago Medical Center, Chicago, IL, USA

nDivision of Cardiology and Department of Radiology, The George Washington University School of Medicine, Washington, DC, USA

oPhilippine Nuclear Research Institute, Quezon City, Philippines

pDivision of Human Health, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria

qSeymour, Paul and Gloria Milstein Division of Cardiology, Department of Medicine, Columbia University Irving Medical Center and NewYork-Presbyterian Hospital, New York, NY, USA

\*Co-first author

**Running Title:** COVID-19 and Global CAD Testing Recovery

**Corresponding Author:**

Todd C. Villines, MD

Professor of Medicine, University of Virginia Health System

PO Box 800158

Charlottesville, VA 22908-0158

Office: 434.297.5973. Fax: 434.982.1998

Email: [tv4bc@virginia.edu](mailto:tv4bc@virginia.edu)

**ABSTRACT**

The COVID-19 pandemic disrupted delivery of cardiovascular care including non-invasive testing protocols and test selection for evaluation of coronary artery disease (CAD). Trends in test selection among traditional versus advanced noninvasive tests for CAD during the pandemic and among countries of varying income status have not been well studied. The International Atomic Energy Agency conducted a global survey to assess pandemic-related changes in the practice of cardiovascular diagnostic testing. Site procedural volumes for noninvasive tests to evaluate CAD from March 2019 (pre-pandemic), April 2020 (onset), and April 2021 (initial recovery) were collected. We considered traditional testing modalities exercise electrocardiography (ECG), stress echocardiography, and stress single-photon emission computed tomography (SPECT), and advanced testing modalities stress cardiac magnetic resonance (CMR), coronary computed tomography angiography (CCTA), and stress positron emission tomography (PET). Survey data were obtained from 669 centers in 107 countries, reporting the performance of 367,933 studies for CAD during the study period. Compared to 2019, traditional tests were performed 14% less frequently (recovery rate 82%) in 2021 versus advanced tests which were performed 15% more frequently (128% recovery rate). CCTA, stress CMR and stress PET showed 14%, 25%, and 25% increases in volumes from 2019 to 2021, respectively. The increase in advanced testing was isolated to high- and upper-middle-income countries, with 132% recovery in advanced tests by 2021 as compared to 55% in lower-income nations. The COVID-19 pandemic exacerbated economic disparities in CAD testing practice between wealthy and poorer countries. Greater recovery rates and even new growth was observed for advanced imaging modalities but this growth was restricted to wealthy countries. Efforts to reduce practice variations in CAD testing due to economic status are warranted.

**Keywords:** cardiac testing, coronavirus, COVID-19, health equity, health disparities

The coronavirus disease 2019 (COVID-19) pandemic severely disrupted the delivery of healthcare across the world.1 The International Atomic Energy Agency (IAEA) Division of Human Health has sought to assess the impact of the pandemic on member states recovery of cardiovascular diagnostic testing in order to address issues of patient access and global heath inequities. Towards this goal, the IAEA formed the International Atomic Energy Agency Non-invasive Cardiology Protocols Study 2 (INCAPS)-COVID 2 study group which has previously documented the impact of COVID-19 on both invasive and non-invasive tests performed for the diagnosis and management of cardiovascular diseases.2-5 These studies have demonstrated that the COVID-19 pandemic resulted in significant disruption to the delivery of pre-pandemic cardiovascular testing volumes, with recovery of invasive and non-invasive testing volumes strongly related to the economic state of member countries.

We sought to extend this prior work by evaluating trends in the use of non-invasive tests for the diagnosis of coronary artery disease (CAD), comparing pre-pandemic, pandemic, and early recovery time periods, to explore trends in test selection over time and according to different geographic and income groups. While traditional non-invasive tests, such stress electrocardiography (ECG), stress echocardiography (SE), or stress single photon emission computed tomography (SPECT), remain the dominant modalities for the diagnosis of CAD advanced tests for CAD, such as coronary computed tomographic angiography (CCTA), cardiac stress magnetic resonance (CMR), or stress positron emission tomography (PET), are being increasingly adopted due to evolving technical maturation, clinical validation, increasing provider expertise, and guideline recommendations.6 These newer technologies may have significant advantages over traditional modalities by providing improved diagnostic accuracy, lower radiation exposure and new clinically relevant information, such as measures of coronary atherosclerotic burden, coronary or myocardial flow-related information, and quantitative tissue characterization.7,8 The impact of the pandemic may have also prompted changes in testing protocols and test selection at many centers. Early in the pandemic, several cardiovascular societies published guidelines on strategies to reduce the spread of COVID-19 during different cardiac testing procedures, with emphasis on avoiding exercise stress testing and consideration of tests with reduced acquisition time, such as cardiac computed tomography.9-11

**Methods**

The INCAPS-COVID 2 study was performed to assess the impact of the COVID-19 pandemic on the worldwide practice of diagnostic cardiovascular testing. A survey was designed by the study Executive Committee whereby facilities that perform diagnostic cardiovascular testing reported procedure volume data for March 2019 (pre-pandemic baseline), April 2020 (early pandemic), and April 2021 (1 year post-pandemic onset), as previously described.2 Based on the high prevalence of non-invasive testing for CAD in global cardiovascular care, the current analysis focused on tests for ischemic heart disease defined as exercise ECG, SE, stress SPECT, stress CMR, stress PET, and CCTA. We categorized CAD testing modalities into traditional and advanced in order to explore potential changes in testing patterns related to the pandemic. We considered exercise ECG, SE, and SPECT to be traditional test modalities as these have been well-established, broadly utilized, require relatively fewer computing capabilities, and tend to be more affordable to perform for institutions. We considered stress CMR, stress PET, and CCTA advanced imaging modalities as they are less broadly utilized or available likely related to relative limitations in equipment, expertise and costs.

Survey data were collected using a standardized data collection form via a secure software platform hosted by the IAEA, the International Research Integration System (IRIS, <https://iris.iaea.org>). Regional and national coordinators were assigned to assist with outreach to IAEA registered institutions and professional organizations to ensure broad and diverse global participation. Country and regional coordinators helped recruit centers in their respective countries and/or regions to increase representation in the study, and a communications committee publicized the study on various social media platforms. Facilities that participated in the first INCAPS-COVID study that compared procedural volumes from 2019 and 2020 were required to submit procedure volume data for April 2021 only, as data for March 2019 and April 2020 were supplied from their original survey responses. Entries were excluded for missing data or incomplete responses to the questionnaire. Data were aggregated at the country and region levels and according to country income levels (low, low-middle, upper-middle and high) as defined by the World Bank classifications. Total volumes of scanner per noninvasive imaging modality per region was obtained from the IAEA IMAGINE survey.12

No patient-specific or confidential data were collected and all participation by study sites was voluntary. The study complies with the Declaration of Helsinki. The Columbia University Institutional Review Board determined that the work does not meet the criteria to be considered human subjects research, as there is no interaction with subjects, no intervention, and private, identifiable information is not being collected.

Recovery rates from early-stage COVID-19-related decreases in procedure volumes were calculated as 100% \* (1 - ((March 2019 volume - April 2021 volume) / (March 2019 volume -April 2020 volume))), as previously described.2 We performed a descriptive analysis to explore the relationship of procedural volumes and recovery rates for the different traditional and advanced CAD diagnostic CAD modalities and the differences in terms of different regions and by world bank income group. Chi-squared tests were performed to compared differences in procedural volumes recovery rates.

Statistical analysis was performed using SAS (Cary, NC, USA) version 9.4, Stata/SE 17.0 (Stata Corporation, LLC, College Station, Texas) and Excel for Microsoft 365 (Redmond, WA, USA). Maps were created using Tableu software (Seattle, WA, USA). The authors had full access to and take full responsibility for the integrity of the data.

**Results**

Characteristics for all participants' centers are summarized in **Table 1**. Worldwide procedural data were analyzed from 669 facilities in 107 countries, with a total of 367,933 non-invasive studies for the diagnosis CAD (165,599 in March 2019, 46,823 in April 2020, and 155,511 in April 2021) performed during the study period. Overall, SPECT was performed in the largest proportion of responding centers (62%), followed by CCTA (48%), and stress ECG (41%), while stress CMR (17%), and stress PET (10%) were performed in the smallest proportion of facilities in 2019. Advanced imaging modalities (≥1 modality) were performed in 505 (75%) centers.

When stratified by region at baseline (2019), centers in the United States (US), Canada, Latin America, and Western Europe had the highest proportion of centers that offered stress CMR. Stress PET was offered in more centers in the US, Canada, and the Middle East. CCTA was offered in higher proportion of centers in the Far East, Latin America, US, Canada, Southeast Asia and Western Europe. Conversely, centers in Africa rarely offered testing other than stress ECG or SPECT imaging, with PET and CMR available in 3% of centers and CCTA and SE in 18%. Similarly, there was significant variability in the availability of scanners by modality across regions, with fewer scanners in Africa, Latin America, and the Middle East.

Overall, noninvasive diagnostic procedure volumes for the diagnosis of CAD decreased 71% from March 2019 to April 2020; however, 91.5% of this worldwide decrease had recovered by April 2021. The change in procedure volumes from March 2019 to April 2021 in each of the traditional and advanced modalities are highlighted in **Figure 1**. Compared to traditional tests for CAD, advanced testing modalities recovered or exceeded pre-pandemic volumes in more geographic regions. Modest (5 to 22%) increases in procedure volumes from 2019 to 2021, associated with recovery rates of 107% to 147%, were observed in Africa and the Far East in total imaging modalities, while in North America (159%) and Western Europe (205%) there was more robust recovery. In contrast, decreases persisted in Latin America (14% decrease from 2019; 83% recovery rate), the Middle East (36% decrease; 53% recovery), and South East Asia (5% decrease; 89% recovery) in all imaging modalities.

Changes in procedure volumes also varied between specific procedure types in terms of traditional vs. advanced modalities. **Figure 2** illustrates that compared to 2019 baseline procedural volumes, traditional modalities suffered a 78% decline in 2020 and were performed 14% less frequently in 2021 than 2019, corresponding to a recovery rate of 82%. In contrast, advanced modalities suffered a 56% decline in 2020 compared to 2019, and were performed 14% more frequently in 2021 than at baseline, with a recovery rate of 128%. Specifically, CCTA, stress CMR and stress PET showed 14%, 25%, and 25% increases in procedural volumes, respectively, compared to 2019 volumes, whereas all other modalities did not increase in their utilization at participating centers. Recovery of advanced modalities was limited to upper-middle and high income countries except for CCTA, which showed growth in low and lower-middle income countries (**Figure 2)**. There were significant differences in recovery of traditional versus advanced testing volume across specific world regions (**Figure 3)**, with Western Europe, the US, Canada, and the Far East showing significantly increased recovery of advanced testing modalities. Among advanced modalities, recovery of cardiac CT exceeded other stress testing modalities in Africa, the Far East, and Latin America. Recovery of stress CMR exceeded other modalities in Western Europe and stress PET recovery rates exceeded other modalities in US and Canada.

We observed significant differences in recovery of all CAD testing modalities between economically disadvantaged and privileged countries. While in 2020, volumes of CAD diagnostic testing procedures decreased among countries of all income levels, by 2021 noninvasive testing for CAD had recovered to exceed pre-COVID-19 levels in high income (178% recovery) and upper-middle-income (147%) countries, compared to recovery rates of 56% and 25% in lower-middle and low income countries, respectively. This difference was larger when comparing advanced to traditional CAD testing modalities where the recovery rate in economically high and upper-middle income countries was 132.1% and 131.8%, respectively, for advanced modalities and 97% and 75%, respectively, for traditional modalities. However, CAD diagnostic testing remained depressed in 2021 in lower-middle incomes countries for advanced (55%) and traditional modalities (43%). In low-income countries, traditional testing volumes recovered 56% compared to 2019 and volumes were insufficient to calculate recovery of advanced tests. **Figure 4** illustrates the differential recovery rates compared to 2019 by income group according to the different traditional (stress ECG, SE, SPECT) and advanced modalities (CMR, CCTA and PET).

The observation of increased recovery in wealthier countries was generally observed across modalities types, with some variation. For example, the growth in CCTA from 2019 to 2021 was limited to upper-middle- and high-income countries, while CCTA procedure volumes decreased by 23% from pre-COVID-19 levels in lower-middle-income countries. The decline in CAD testing was more profound in least developed countries, whereas CCTA, PET and cardiac MRI stress testing increased from pre-COVID-19 levels in upper-middle- and high-income countries. Exercise ECG and stress SPECT did not recover to pre-pandemic volumes in wealthier countries, with recovery rates of 81 to 90% and 58 to 93% in upper-middle and high-income countries, respectively.

**Discussion**

We have shown important global differences in the recovery of advanced and traditional noninvasive tests for CAD during the COVID-19 pandemic in a survey of 669 inpatient and outpatient facilities in 107 countries. We observed a reduction of 72% in noninvasive imaging for CAD early in the pandemic, with a noticeable recovery of 92% worldwide after one year. Importantly, recovery patterns varied significantly according to economic resources, with less robust recovery in economically disadvantaged countries than in more privileged countries. This was particularly apparent in the recovery of advanced imaging tests compared to traditional tests. Specifically, advanced modalities had a recovery rate of 128%, compared to traditional modalities (82%), a difference that was exacerbated when comparing lower versus higher income countries. This finding highlights the growing significant inequality in global practice of non-invasive testing for CAD and requires further study. Not surprisingly, centers self-identified as teaching facilities had significantly increased growth in utilization of advanced testing modalities. Interestingly, exercise testing has not recovered even in more privileged countries. This may be related to the potential risk of aerosolization during exercise stress testing or a more general shift away from stress ECG to imaging tests for CAD as outlined in recent guidelines.

These findings have important implications for global cardiovascular health. First, advanced tests may, in some patients, offer diagnostic advantages compared to some traditional tests for CAD. These advantages include increased diagnostic accuracy, lower radiation exposure, and the potential to obtain additional diagnostic information, such as advanced measures of blood flow (e.g., coronary and myocardial flow reserves). In a meta-analysis comparing the diagnostic performance of different imaging techniques for CAD, it was found that PET achieved the highest diagnostic performance, while CMR had similar diagnostic accuracy as PET but without ionizing radiation.13 Recent international guidelines for CAD also recommend many advanced CAD tests as first-line options for symptomatic patients.7,14 For example, in the US multisocietal chest pain guideline, stress PET is recommended in lieu of stress SPECT when available, based on higher diagnostic accuracy and lower radiation exposure.7 Hence, the lack of available advanced testing options in many countries represents a form of healthcare inequality which may translate to increased rates of preventable adverse cardiovascular outcomes and decreased diagnostic certainty among patients and providers. Efforts by international agencies, as well as medical societies, should focus on improving the availability of testing hardware, software, education, and training opportunities for medical providers and healthcare leaders. These efforts should also include work to identify local and national/regional barriers to providing more diverse CAD test options, including increasing availability of CCTA, CMR, and cardiac PET. Well-educated, trained providers will make more optimal testing choices for CAD when all forms of testing are available and performed at a high level of quality.

There are probably many reasons for the differences in recovery rates in different modalities through different regions and income levels, such as the preexisting state of a health system, the number of scanners available, and local expertise. Pre-pandemic studies showed that some of the regional variation patterns may result from variability in expertise among cardiac images and imaging equipment availability.15 Efforts should be made to identify additional factors that have accentuated this gap in the utilization of more advanced modalities in lower-income regions. Our study provides new insights into the pandemic-related changes in utilization in cardiac testing and emphasizes that future research is needed to better understand the differences across countries and regions related to noninvasive testing strategies for CAD, and to follow the worldwide trends first identified here, as will be done in the forthcoming INCAPS 4 study. Cardiology health disparities may translate into differential cardiovascular outcomes attributable to systemic, avoidable, and unjust societal factors and structural policies.16 Efforts should be made to coordinate collaborative efforts to create the necessary policy changes and opportunities to advance health equity. We hope that medical and cardiovascular imaging societies and radiology and cardiology communities will join efforts to reduce inequity in access to the most advanced modalities for better care of patients with heart disease.

Due to the nature of survey research, there is inherent risk in selection and recall bias, as well as inaccuracies in procedural volume reporting from participating sites (procedural numbers were not verified). Additionally, the number of responses from low-income countries and some regions, such as Africa, was small, likely reflective of less testing availability, as verified by the number of available scanners, in these world regions. This skewed distribution, with significantly few centers participating from low and low-middle income countries, limited the statistical robustness of attempts to model recovery using a multivariable model. The pandemic also varied in its intensity and timing across world regions making it likely that survey responses from a specific month may reflect sites at different pandemic phases. The observed increase in advanced testing volumes may also reflect changes in international guidelines for the diagnosis of CAD, reimbursement, as well as the natural proliferation of scanner technology and trained personnel performing more advanced tests over time, while traditional testing changes are more representative of change related purely to COVID-19. It is important to note that the appropriate use for performed tests was not assessed as part of this survey and increased use of advanced tests may not relate to improvements in patient outcomes. Lastly, the authors associated testing sites within a country to the national income level as defined by the World Bank and acknowledge that there may be significant variability in resources at sites within countries and regions of the world.

Worldwide, there was a 92% recovery in CAD noninvasive diagnostic testing procedure volumes from the onset of the COVID-19 pandemic to April 2021. However, complete recovery was primarily observed in high- and upper-middle income countries, whereas procedure volumes in low- and lower-middle-income countries had yet to recover during the survey period. Greater recovery rates and even new growth was observed for advanced imaging modalities, stress MRI, stress PET, and CCTA, mainly in upper-middle and high-income countries, a phenomenon not observer in poorer countries. The permanency of lagging recovery for other modalities, such as SPECT, and exercise ECG stress testing, remains unknown and may reflect a shift in diagnostic testing strategies since the onset of the COVID-19 pandemic. Efforts to address worldwide disparities in CAD testing availability are needed.

**Acknowledgements**

The INCAPS-COVID 2 Investigators Group, listed by name in the Appendix, thank cardiology and imaging professional societies worldwide for their assistance in disseminating the survey to their memberships. These include alphabetically, but are not limited to, American Society of Nuclear Cardiology, Arab Society of Nuclear Medicine, Australasian Association of Nuclear Medicine Specialists, Australia-New Zealand Society of Nuclear Medicine, Belgian Society of Nuclear Medicine, Brazilian Nuclear Medicine Society, British Society of Cardiovascular Imaging, Conjoint Committee for the Recognition of Training in CT Coronary Angiography, Consortium of Universities and Institutions in Japan, Gruppo Italiano Cardiologia Nucleare, Indonesian Society of Nuclear Medicine, Japanese Society of Nuclear Cardiology, Philippine Society of Nuclear Medicine, Russian Society of Radiology, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Thailand Society of Nuclear Medicine. MCW (FS/ICRF/20/26002) is supported by the British Heart Foundation.

**Sources of Funding:**

The primary source of indirect funding for the study was from the Division of Human Health, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria. PRL receives funding as an iTHRIV Scholar. The iTHRIV Scholars Program is supported in part by the National Center for Advancing Translational Sciences of the National Institutes of Health under Award Numbers UL1TR003015 and KL2TR003016.

**Disclosures:**

TCV is an employee of Elucid Bioimaging and has separately received authorship fees from Wolters Kluwer Healthcare-UpToDate. MCW has given talks for Canon Medical Systems, Siemens Healthineers and Novartis. AJE reports receiving a speaker's fee from Ionetix, consulting fees from W. L. Gore & Associates, authorship fees from Wolters Kluwer Healthcare—UpToDate, and serving on a scientific advisory board for Canon Medical Systems USA; his institution has grants/grants pending from Attralus, Bruker, Canon Medical Systems USA, Eidos Therapeutics, GE Healthcare, Intellia Therapeutics, Ionis Pharmaceuticals, Neovasc, Pfizer, Roche Medical Systems, and W. L. Gore & Associates.

References

**1.** Moynihan R, Sanders S, Michaleff ZA, Scott AM, Clark J, To EJ, Jones M, Kitchener E, Fox M, Johansson M, Lang E, Duggan A, Scott I, Albarqouni L. Impact of COVID-19 pandemic on utilisation of healthcare services: a systematic review. *BMJ Open* 2021;11:e045343.

**2.** Einstein AJ, Hirschfeld C, Williams MC, Vitola JV, Better N, Villines TC, Cerci R, Shaw LJ, Choi AD, Dorbala S, Karthikeyan G, Lu B, Sinitsyn V, Ansheles AA, Kudo T, Bucciarelli-Ducci C, Norgaard BL, Maurovich-Horvat P, Campisi R, Milan E, Louw L, Allam AH, Bhatia M, Sewanan L, Malkovskiy E, Cohen Y, Randazzo M, Narula J, Morozova O, Pascual TNB, Pynda Y, Dondi M, Paez D, Group ICI. Worldwide Disparities in Recovery of Cardiac Testing 1 Year Into COVID-19. *J Am Coll Cardiol* 2022;79:2001-2017.

**3.** Hirschfeld CB, Shaw LJ, Williams MC, Lahey R, Villines TC, Dorbala S, Choi AD, Shah NR, Bluemke DA, Berman DS, Blankstein R, Ferencik M, Narula J, Winchester D, Malkovskiy E, Goebel B, Randazzo MJ, Lopez-Mattei J, Parwani P, Vitola JV, Cerci RJ, Better N, Raggi P, Lu B, Sergienko V, Sinitsyn V, Kudo T, Norgaard BL, Maurovich-Horvat P, Cohen YA, Pascual TNB, Pynda Y, Dondi M, Paez D, Einstein AJ, Group I-CI. Impact of COVID-19 on Cardiovascular Testing in the United States Versus the Rest of the World. *JACC Cardiovasc Imaging* 2021;14:1787-1799.

**4.** Kudo T, Lahey R, Hirschfeld CB, Williams MC, Lu B, Alasnag M, Bhatia M, Henry Bom HS, Dautov T, Fazel R, Karthikeyan G, Keng FYJ, Rubinshtein R, Better N, Cerci RJ, Dorbala S, Raggi P, Shaw LJ, Villines TC, Vitola JV, Choi AD, Malkovskiy E, Goebel B, Cohen YA, Randazzo M, Pascual TNB, Pynda Y, Dondi M, Paez D, Einstein AJ, Group ICI. Impact of COVID-19 Pandemic on Cardiovascular Testing in Asia: The IAEA INCAPS-COVID Study. *JACC Asia* 2021;1:187-199.

**5.** Williams MC, Shaw L, Hirschfeld CB, Maurovich-Horvat P, Norgaard BL, Pontone G, Jimenez-Heffernan A, Sinitsyn V, Sergienko V, Ansheles A, Bax JJ, Buechel R, Milan E, Slart R, Nicol E, Bucciarelli-Ducci C, Pynda Y, Better N, Cerci R, Dorbala S, Raggi P, Villines TC, Vitola J, Malkovskiy E, Goebel B, Cohen Y, Randazzo M, Pascual TNB, Dondi M, Paez D, Einstein AJ, Group ICI. Impact of COVID-19 on the imaging diagnosis of cardiac disease in Europe. *Open Heart* 2021;8.

**6.** Reeves RA, Halpern EJ, Rao VM. Cardiac Imaging Trends from 2010 to 2019 in the Medicare Population. *Radiol Cardiothorac Imaging* 2021;3:e210156.

**7.** Writing Committee M, Gulati M, Levy PD, Mukherjee D, Amsterdam E, Bhatt DL, Birtcher KK, Blankstein R, Boyd J, Bullock-Palmer RP, Conejo T, Diercks DB, Gentile F, Greenwood JP, Hess EP, Hollenberg SM, Jaber WA, Jneid H, Joglar JA, Morrow DA, O'Connor RE, Ross MA, Shaw LJ. 2021 AHA/ACC/ASE/CHEST/SAEM/SCCT/SCMR Guideline for the Evaluation and Diagnosis of Chest Pain: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. *J Am Coll Cardiol* 2021;78:e187-e285.

**8.** Sirajuddin A, Mirmomen SM, Kligerman SJ, Groves DW, Burke AP, Kureshi F, White CS, Arai AE. Ischemic Heart Disease: Noninvasive Imaging Techniques and Findings. *RadioGraphics* 2021;41:990-1021.

**9.** Choi AD, Abbara S, Branch KR, Feuchtner GM, Ghoshhajra B, Nieman K, Pontone G, Villines TC, Williams MC, Blankstein R. Society of Cardiovascular Computed Tomography guidance for use of cardiac computed tomography amidst the COVID-19 pandemic Endorsed by the American College of Cardiology. *J Cardiovasc Comput Tomogr* 2020;14:101-104.

**10.** Skali H, Murthy VL, Paez D, Choi EM, Keng FYJ, Iain MA, Al-Mallah M, Campisi R, Bateman TM, Carrio I, Beanlands R, Calnon DA, Dilsizian V, Dondi M, Gimelli A, Pagnanelli R, Polk DM, Soman P, Einstein AJ, Dorbala S, Thompson RC. Guidance and best practices for reestablishment of non-emergent care in nuclear cardiology laboratories during the coronavirus disease 2019 (COVID-19) pandemic: An information statement from ASNC, IAEA, and SNMMI : Endorsed by the Infectious Diseases Society of America. *J Nucl Cardiol* 2020;27:1855-1862.

**11.** Task Force for the management of C-otESoC. ESC guidance for the diagnosis and management of cardiovascular disease during the COVID-19 pandemic: part 2-care pathways, treatment, and follow-up. *Cardiovasc Res* 2022;118:1618-1666.

**12.** IMAGINE - IAEA Medical imAGIng and Nuclear mEdicine global resources database.

**13.** Jaarsma C, Leiner T, Bekkers SC, Crijns HJ, Wildberger JE, Nagel E, Nelemans PJ, Schalla S. Diagnostic Performance of Noninvasive Myocardial Perfusion Imaging Using Single-Photon Emission Computed Tomography, Cardiac Magnetic Resonance, and Positron Emission Tomography Imaging for the Detection of Obstructive Coronary Artery Disease. *Journal of the American College of Cardiology* 2012;59:1719-1728.

**14.** Knuuti J, Wijns W, Saraste A, Capodanno D, Barbato E, Funck-Brentano C, Prescott E, Storey RF, Deaton C, Cuisset T, Agewall S, Dickstein K, Edvardsen T, Escaned J, Gersh BJ, Svitil P, Gilard M, Hasdai D, Hatala R, Mahfoud F, Masip J, Muneretto C, Valgimigli M, Achenbach S, Bax JJ, Group ESCSD. 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes. *Eur Heart J* 2020;41:407-477.

**15.** Shaw LJ, Blankstein R, Jacobs JE, Leipsic JA, Kwong RY, Taqueti VR, Beanlands RSB, Mieres JH, Flamm SD, Gerber TC, Spertus J, Carli MFD. Defining Quality in Cardiovascular Imaging: A Scientific Statement From the American Heart Association. *Circulation: Cardiovascular Imaging* 2017;10:e000017.

**16.** Itchhaporia D. Paving the Way for Health Equity in Cardiology. *Journal of the American College of Cardiology* 2021;77:2613-2616.

**Figure Legends**

**Figure 1. Worldwide changes in traditional vs. advanced testing procedures volumes from March 2019 to April 2021**

World map demonstrating changes in total cardiovascular procedural volume from March 2019 to April 2021 across the 107 participating countries. Countries or territories of a country with no color did not have data available. The procedures included are coronary CTA (CCT) and stress testing (exercise electrocardiogram [ECG], positron emission tomography, single photon emission computed tomography, stress cardiac magnetic resonance, and stress echocardiography)

**Figure 2. Change from baseline (2019) procedure volumes during the early phase of the pandemic (2020) and one year later (2021)\***

\*Traditional modalities (stress ECG, stress echocardiography, stress SPECT) and advanced modalities (stress PET, stress CMR, CCTA).

**Figure 3. Traditional versus advanced\* testing volume recovery (2019 versus 2021) by region**

Recovery rates were calculated based on the total number of traditional and advanced imagine for each region. P-values are calculated using center level recovery rates for each region.

\*Traditional modalities (stress ECG, stress echocardiography, stress SPECT) and advanced modalities (stress PET, stress CMR, CCTA).

**Figure 4. Procedure volume recovery rate compared to 2019 by World Bank income group**

\*The procedures included are traditional modalities (stress ECG, stress echocardiography, stress SPECT) and advanced modalities (stress PET, stress CMR, CCTA).

**Table 1: Characteristics of Participating Centers**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Total** | **Africa** | **Eastern Europe** | **Far East** | **Latin America** | **Middle East and South Asia** | **US and Canada** | **Southeast Asia and Pacific** | **Western Europe** |
| **Numbers of centers** | 669 | 38 | 53 | 82 | 135 | 63 | 102 | 45 | 151 |
| **Numbers of countries** | 107 | 14 | 21 | 7 | 19 | 15 | 2 | 9 | 20 |
|  |  |  |  |  |  |  |  |  |  |
| **Numbers of total imaging tests for CAD** |  |  |  |  |  |  |  |  |  |
| March 2019 | 165,599 | 4,685 | 7,569 | 23,804 | 50,574 | 13,616 | 29,518 | 9,063 | 26,770 |
| April 2020 | 46,823 | 1,164 | 1,900 | 12,844 | 9,502 | 2,718 | 7,210 | 3,725 | 7,760 |
| April 2021 | 155,511 | 4,049 | 8,128 | 28,927 | 38,727 | 7,450 | 311,76 | 6,954 | 30,100 |
|  |  |  |  |  |  |  |  |  |  |
| **Numbers of traditional tests** |  |  |  |  |  |  |  |  |  |
| March 2019 | 119,641 | 3,717 | 5,180 | 6,542 | 44,683 | 11,586 | 22,174 | 7,211 | 18,548 |
| April 2020 | 26,435 | 807 | 1,083 | 3,011 | 7,761 | 2,057 | 4,284 | 2,718 | 4,714 |
| April 2021 | 102,402 | 3,090 | 5,756 | 7,266 | 32,773 | 5,869 | 21,933 | 5,457 | 20,258 |
| **Numbers of advanced tests** |  |  |  |  |  |  |  |  |  |
| March 2019 | 45,958 | 968 | 2,389 | 17,262 | 5,891 | 2,030 | 7,344 | 1,852 | 8,222 |
| April 2020 | 20,388 | 357 | 817 | 9,833 | 1,741 | 661 | 2,926 | 1,007 | 3,046 |
| April 2021 | 53,109 | 959 | 2,372 | 21,661 | 5,954 | 1,581 | 9,243 | 1,497 | 9,842 |
|  |  |  |  |  |  |  |  |  |  |
| **Teaching institution, n (%)** | 475 (71) | 25 (66) | 38 (72) | 63 (77) | 74 (55) | 48 (76) | 74 (73) | 33 (73) | 120 (79) |
|  |  |  |  |  |  |  |  |  |  |
| **Economic level by centers, n (%)** |  |  |  |  |  |  |  |  |  |
| Low | 7 (1) | 6 (16) | 0 (0) | 0 (0) | 0 (0) | 1 (2) | 0 (0) | 0 (0) | 0 (0) |
| Low-middle | 81 (12) | 19 (50) | 3 (6) | 14 (17) | 4 (3) | 37 (59) | 0 (0) | 4 (9) | 0 (0) |
| Upper-middle | 198 (30) | 12 (32) | 26 (49) | 17 (21) | 125 (93) | 9 (14) | 0 (0) | 7 (16) | 2 (1) |
| Upper | 383 (57) | 1 (3) | 24 (45) | 51 (62) | 6 (4) | 16 (25) | 102 (100) | 34 (76) | 149 (99) |
|  |  |  |  |  |  |  |  |  |  |
| **Number of centers performing each modality, n (%)\*** |  |  |  |  |  |  |  |  |  |
| Stress ECG | 273 (41) | 15 (39) | 13 (25) | 30 (37) | 50 (37) | 25 (40) | 60 (59%) | 14 (31) | 66 (44) |
| Stress Echocardiography | 220 (33) | 7 (18) | 13 (25) | 21 (26) | 21 (26) | 21 (33) | 57 (56%) | 15 (33) | 52 (34) |
| Stress SPECT | 414 (62) | 17 (45) | 29 (55) | 48 (59) | 86 (64) | 36 (57) | 75 (74%) | 34 (76) | 89 (59) |
| Stress PET | 65 (10) | 1 (3) | 2 (4) | 3 (4) | 7 (5) | 12 (19) | 26 (25%) | 0 (0) | 14 (9) |
| Stress CMR | 117 (17) | 1 (3) | 7 (13) | 6 (7) | 32 (24) | 6 (10) | 26 (25%) | 3 (7) | 36 (24) |
| Coronary CT angiography | 323 (48) | 7 (18) | 22 (42) | 53 (65) | 56 (41) | 24 (38) | 60 (59%) | 24 (53) | 77 (51) |
|  |  |  |  |  |  |  |  |  |  |
| **Scanner availability\*\*** |  |  |  |  |  |  |  |  |  |
| Number of SPECT scanners | 22795 | 328 | 1036 | 1913 | 382 | 145 | 14825 | 360 | 3806 |
| Number of PET scanners | 4674 | 65 | 170 | 662 | 73 | 44 | 2400 | 134 | 1126 |
| Number of MRI scanners | 36765 | 921 | 2605 | 8177 | 446 | 545 | 12234 | 710 | 11127 |
| Number of CT scanners | 56859 | 3316 | 5514 | 16037 | 1051 | 962 | 13889 | 2673 | 13417 |