Clinical and Translational Imaging
https://doi.org/10.1007/s40336-022-00531-7

SYSTEMATIC REVIEW

Myocardial perfusion imaging in the era of COVID-19: a systematic review

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Received: 18 August 2022 / Accepted: 4 November 2022

Abstract

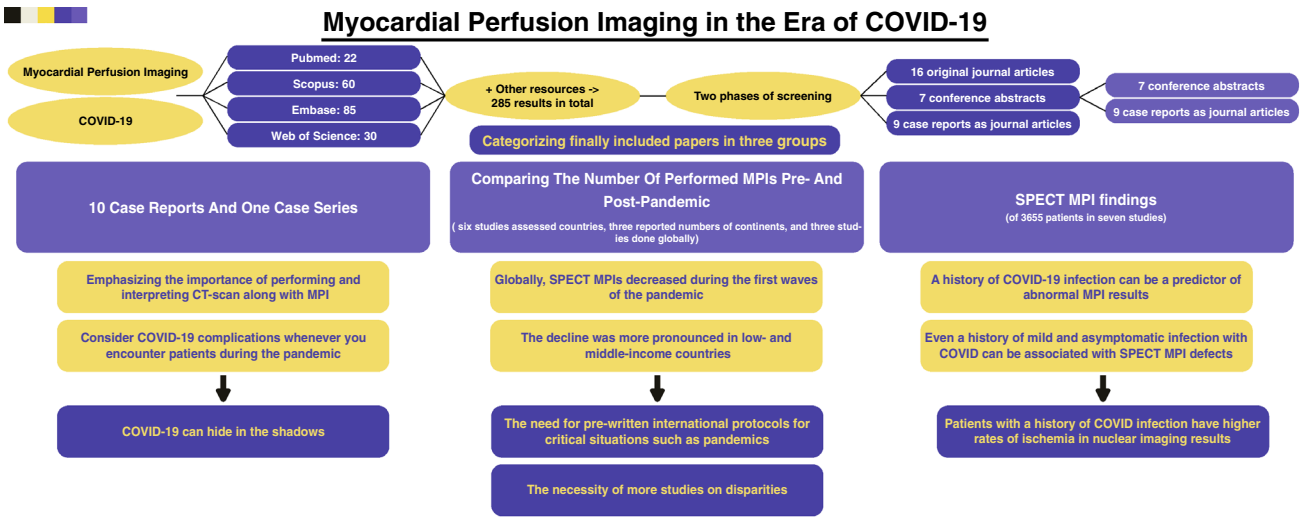
Purpose As COVID-19 was uncovered, it became evident that specific individuals could experience multi-organ complications for quite a while after infection. Among them, there were several cardiovascular complications. Myocardial perfusion imaging single photon emission computed tomography (MPI SPECT) can be utilized to detect and evaluate cardiac problems regardless of whether COVID caused them. By examining all publications relevant to the impacts of the pandemic on SPECT MPI imaging, we aimed to understand how the COVID pandemic affected different aspects of the MPI, how intense these effects were, and what the consequences were.

Method On the 6th of June, 2022, a four-domain search strategy was developed and implemented by searching the following databases: PubMed, SCOPUS, EMBASE, Web of Science, and the Cochrane Central Register of Controlled Trials. The retrieved records have been put through two levels of screening. The search for forward and backward citations provided more results.

Results This study contained 32 papers, divided into the following three categories: 1. Case reports and series; 2. A comparison of the number of MPIs conducted before and after the pandemic; and 3. SPECT MPI findings.

Conclusion We observed through the article review that CT scans performed in combination with MPI are crucial and should be interpreted within the context of COVID, especially during outbreaks. Moreover, we discovered that in the initial months of the pandemic, the number of SPECT MPIs performed globally decreased, with the fall being more significant in some countries, primarily in low- to middle-income regions. Lastly, we found that individuals with a history of COVID-19 may be more prone to having MPIs that demonstrate abnormalities, such as ischemia.

Graphical abstract



Keywords Myocardial perfusion imaging · COVID-19 · Systematic review

Extended author information available on the last page of the article

Published online: 15 December 2022

Introduction

The first reports of this outbreak focused primarily on typical symptoms of influenza-like illness in patients with COVID-19, such as dry cough, fever, and fatigue [1].

In early 2020, a Chinese case report presented the first COVID-19 patient with cardiovascular injuries who died because of fulminant myocarditis [2]. However, later, researchers and scientists discussed cardiac injuries and their possible pathology and etiology in COVID-19 [3, 4].

There are several imaging modalities for diagnosing and evaluating different cardiovascular injuries caused by COVID-19 [5, 6]. It is still recommended that un-urgent and elective cardiac imaging be postponed in patients who are known cases of COVID-19 or are suspected to be [7, 8]. The use of cardiac imaging in positive or suspicious COVID-19 cases should only be considered if the imaging results affect the patient's management plan [5].

When indicated [9], one of the cardiac imaging modalities used is myocardial perfusion imaging (MPI). MPI, which is done by Single Photon Emission Computed Tomography (SPECT), is the most frequently applied nuclear cardiac imaging technique [10]. There are now 27,180 SPECT scanners worldwide in 141 countries [11].

Major indications of using myocardial SPECT are diagnosing coronary artery disease (CAD), risk stratification in patients with known CAD or after myocardial infarction or before non-cardiac surgeries, and assessment of intervention and myocardial viability before bypass or percutaneous surgery [12]. It can also diagnose ACS in emergency departments, assess ischemia in patients who had successful revascularization but had a recurrence of symptoms [13], and evaluate dyspnea with a possible cardiovascular cause [14]. MPI can be utilized to assess cardiovascular damage in COVID-19 or, as indicated before the pandemic, for non-COVID patients [15].

To perform MPI based on predetermined priorities in the COVID-19 era, it is necessary to take some measurements at various stages as follows: prior to the patient's arrival at the imaging facility, upon entry, during the imaging process, and after that. By taking these measures, infected and suspicious patients, covid-negative patients, and employees can be protected by decreasing their COVID-19 exposure [16–20]. As the back-to-normal situation advances, some of these measures will be adopted [21].

Guidelines for nuclear cardiology advocate against exercise stress testing in MPI in the era of COVID-19. Instead, they should use pharmacological stress tests with vasodilators to minimize droplet exposure to staff and reduce close contact between patients and staff. In addition, it is recommended to employ attenuation-corrected imaging during the COVID-19 pandemic. It is crucial to interpret CT scans taken for attenuation correction in the context of pulmonary COVID findings prior to discharge [19, 22], as COVID-19 pulmonary findings can occur in asymptomatic patients [18].

In light of the published guidelines and best practices to conduct SPECT MPI in the era of COVID-19, some of which were mentioned above, a broad research question has emerged as follows: has the COVID pandemic affected the cardiac nuclear imaging community and their patients? Moreover, what are the likely consequences of such a change if that is the case? The authors' primary searches revealed that, to the best of our knowledge, not all of the effects of the pandemic on the SPECT MPI imaging community had been examined in one broad framework simultaneously. We aimed to address this fundamental question for the following reason : to determine what effects the COVID pandemic had on various aspects of spect MPI and how intense these effects were. This is due to the fact that the COVID pandemic is still ongoing, and there is still a possibility of subsequent waves worldwide or regionally.

Material and methods

The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) Statement was followed in the reporting of this systematic review.

An electronic version of this systematic review protocol is available in The International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY®) (https://doi.org/10.37766/inplasy2022.4.0063).

We included all English studies regardless of their study design, whether they were experimental or observational of all types, both original articles and conference abstracts. Exclusion criteria were as follows:

- Written in any language other than English.
- Theses, book chapters, editorials, and letters.

In accordance with the PICO framework, participants were defined as anyone who had experienced SPECT MPI anywhere in the world since the COVID-19 pandemic, regardless of their age, gender, race, or health status. The intervention was SPECT MPI in any setting, regardless of whether it was performed at rest or under stress. Other nuclear cardiology imaging methods, such as positron emission tomography (PET), were not included in the study. Moreover, records of SPECT findings outside the myocardium were excluded. The comparators for this study included the number of SPECT MPIs done during the pandemic, the results of MPIs in COVID patients versus those without COVID, or any other aspect of SPECT MPI.

The primary outcomes were as follows:

- Comparing the number of MPIs in multiple regions around the world before and during the pandemic,
- MPI findings in COVID-19 patients, in long-COVID cases, or in cases that were COVID-positive before.

The secondary outcomes were as follows:

- A comparison of the increasing or decreasing trend among different regions of the world in terms of the number of SPECT MPIs performed
- Diagnosis of COVID-19 as an incidental finding in attention correction CT with MPI SPECT imaging
- Any other aspects of SPECT MPI which are influenced by the COVID-19 pandemic and its margins
- Case series and case reports about any aspect of SPECT MPI in the era of COVID-19.

We searched PubMed, Scopus, Embase, the Web of Science, and the Cochrane Central Register of Controlled Trials (from Ovid) on June 6th, 2022. Additionally, we searched clinicaltrials.gov to see if any trials were currently underway. We looked for similar reviews in Prospero and Inplasy. Neither date nor language filters was used during these searches.

To begin with, we conducted a sensitive PubMed search with four domains using the following components:

A: Synonymous terms for COVID-19 and SARS-CoronoVirus-2: "post-acute COVID-19 syndrome" as supplementary concept, "COVID-19" as MeSH, and using title/abstract search filter for the terms: "covid", "long-covid", "long-haul covid", long hauler covid", "post acute covid", "persistent covid", chronic covid", "sars-cov-2", "2019-ncov", corona virus", "severe acute respiratory syndrome coronavirus", "post-covid", and representations synonyms or similar to these terms

B: Myocardial perfusion imaging and its analogs: "Myocardial Perfusion Imaging" and "Cardiac-Gated Single-Photon Emission Computer-Assisted Tomography" MeSHes, and using title/abstract search filter for the following terms: "myocardial scintigraphy", "myocardial perfusion scintigraphy", myocardial mibg scintigraphy", "gmps", myocardial ct perfusion", "sestamibi myocardial scintigraphy", "myocardial perfusion single-photon emission computed tomography", "myocardial perfusion spect", myocardial first-pass perfusion imaging", "cardiac-gated spect", and any terms synonyms or similar to these

C: For SPECT and other related terms, we used "Single Photon Emission Computed Tomography" and "Perfusion Imaging" as MeSHes, and synonyms and similar terms for "spect" and "specs" using title/abstract search filters

D: Myocardium, as a MeSH term and with the title/abstract search filter.

Our search string was A and (B OR (C and D)); Table 1 lists the entire PubMed search string. All authors (AH, SH, and SSN) conducted this primary search string together through a virtual meeting via Google Meet and using the "rain of thoughts" technique; all authors (AH, SH, and SSN) conducted this primary search string together.

Under the supervision of another author (SH), an author (AH) translated the search strategy from PubMed's specified advance-search language to other databases'. Appendix A provides all the search strings for all databases.

After developing search strings for all databases, on June 6, 2022, one of the authors (AH) retrieved all records from the databases. "Journal of Nuclear Cardiology" and "European Journal of Nuclear Medicine and Molecular Imaging" had the most search results using the Scopus database's "Source title" filter (12 and 5 records, respectively). We also searched the Web of Science database using the "Publication Titles" filter. Each journal had five records, indicating that the two journals with the most relevant results were the same, each with five related records. As a result, we determined that these two journals contained the most relevant search results. As those journals were registered in PubMed, we ran two more sensitive searches on June 6th, 2022, in PubMed for those two journals, which are available in Appendix B.

After adding all results to the resulting pool, one of the authors (AH) imported them to a newly created library in EndNote version 20 and performed an automated duplicate finding with the EndNote default settings. The remaining records were then sorted alphabetically from A to Z in the library, and the first and second authors separately looked through titles (and, if necessary, abstracts and full texts) to eliminate duplicates.

The remaining records were imported into Rayyan, a free web tool designed to help researchers with systematic reviews [23], and two of the authors (AH and SH) screened them separately by title and abstract. Any records that did not fit our study questions' scope were removed. All not-excluded records are tagged as "may be included."

One author (AH) transferred the records extracted from Rayyan to a library in Endnote, titled "maybe included," and searched for any more probable relevant records in both the references to the records and the articles that cited them using Google Scholar. This approach, called "forward and backward citation search," was done in 3 days by June 12th, 2022, and more articles were added to the "maybe included" library of Endnote. Following another automated duplicate detection, the library was sent to Rayyan for the second screening step.

Records were screened independently by two of the authors (AH and SH) based on full texts provided by another

Table 1 Main search strategy developing

Domain	Term(s)	Search string	Number of results (Pubmed)
A	COVID-19, long-COVID, or SARS-Corona Virus-2	*"post-acute COVID-19 syndrome" [Supplementary Concept] OR "COVID-19"[Mesh] OR covid*[tiab] OR covid-19[tiab] OR covid-19[tiab] OR "long-covid*"[tiab] OR "long-haul covid*"[tiab] OR "post-acute covid*"[tiab] OR "persistent covid*"[tiab] OR "long covid*"[tiab] OR "long haul covid*"[tiab] OR "long hauler covid*"[tiab] OR "post acute covid*"[tiab] OR "persistent covid*"[tiab] OR "chronic covid*"[tiab] OR "sars-cov-2"[tiab] OR "2019-ncov"[tiab] OR "corona virus"[tiab] OR "coronavirus"[tiab] OR "novel coronavirus"[tiab] OR "ncov-2019"[tiab] OR "severe acute respiratory syndrome coronavirus"[tiab] OR "postcovid*"[tiab] OR "post covid*"[tiab] OR "post-covid*"[tiab]*	277,655
B	Myocardial SPECT	*"Myocardial Perfusion Imaging"[Mesh] OR "myocardial perfusion imaging"[tiab] OR "myocardial perfusion scan"[tiab] OR "myocardial scintigraphy"[tiab] OR "myocardial perfusion scintigraphy"[tiab] OR "myocardial mibg scintigraphy"[tiab] OR gmps[tiab] OR "myocardial ct perfusion"[tiab] OR "sestamibi myocardial scintigraphy"[tiab] OR "myocardial perfusion single-photon emission computed tomography"[tiab] OR "myocardial perfusion spect"[tiab] OR "spect myocardial perfusion"[tiab] OR "myocardial first-pass perfusion imaging"[tiab] OR "Cardiac-Gated Single-Photon Emission Computer-Assisted Tomography"[Mesh] OR "cardiac gated single photon emission computer assisted tomography"[tiab] OR "cardiac-gated spect"[tiab] OR "cardiac gated spect"[tiab]*	12,528
C	SPECT	*"Single Photon Emission Computed Tomography Computed Tomography"[Mesh] OR "single photon emission computed tomography"[tiab] OR spect[tiab] OR specs[tiab] OR "Perfusion Imaging"[Mesh]*	42,511
D	Myocardium	*"Myocardium"[Mesh] OR myocard*[tiab]*	538,990
C and D	Myocardial SPECT		10,855
B or (C and D)	Myocardial SPECT		16,552
A and (B or (C and D))	COVID-19 (or long-COVID or SARS-CoV-2) and Myocardial SPECT		22

author (SSN). "Included" was tagged to all records that met inclusion criteria and did not have exclusion criteria. Excluded articles were specified with their reasons for exclusion. The two authors talked about their disagreements about screening and tried to develop a consensus-based solution. Any remaining disagreements were brought to the third author (SNN) for a final resolution.

In Microsoft Excel, one of the authors (AH) created a data-extraction form containing bibliographic information (title, first author, DOI, year, journal, country, type of article), the study design, as well as the findings, results, and the conclusion of the studies.

Having finalized the process of selecting records, two of the authors (AH and SH) filled out the data-extraction form with all selected records, each on one line. The differences between the two were discussed and resolved after finalizing the data entry.

In order to assess the risk of bias in all included studies, two authors (AH and SH) independently used critical appraisal tools developed by the Joanna Briggs Institute (jbi.

global/critical-appraisal-tools). We evaluated and scored analytical cross-sectional, case–control, case reports, case series, cohorts, and prevalence cross-sectional studies using the JBI Checklists for Analytical Cross-Sectional Studies (8 questions), the Case–Control Checklist (10 questions), and the Case Report Checklist (8 questions), the Case Series Checklist (10 questions), the Cohort Study Checklist (11 questions), and the Prevalence Study Checklist (9 questions), respectively.

Considering the heterogeneity of study designs and types included in this review, as well as the different checklists utilized with different maximum scores, we calculated the net score by dividing each paper's score by the maximum score it can achieve based on its checklist. It has been done to make comparisons and reporting easier. Here, *low-quality* scores are determined as less than 1/3, *medium-quality* scores are defined as between one-third and two-thirds, and *high-quality* scores are defined as over two-thirds.

Study selection

Among the 285 papers included in our record pool, 201 were obtained from searching electronic databases, including 22 records from PubMed, 60 records from SCOPUS, 85 from Embase, 30 from the Web of Sciences, and four from searches of the Cochrane Central Register of Controlled Trials accessed through Ovid. Alongside the search of the main databases, we retrieved 84 records from other sources, including three completed studies on the clinicaltrials.gov website, eight records from the Nuclear Cardiology journal, and 73 records from the European Journal of Nuclear Medicine and Molecular Imaging.

A total of 119 duplicate records have been omitted from these 285 records, 115 by the automated duplicate finder in Endnote version 20, and four by hand. We screened the remaining 116 papers according to their title and abstract. One hundred three records were excluded and identified as irrelevant at this stage, and 63 records received approval for inclusion eligibility screening based on review of full texts. Using forward and backward citation methods, we searched through these 63 records, and, as a result, seven new unduplicated papers were added to our pool, making 70 full texts eligible for inclusion screening. In this stage, 38 papers were excluded; of those, 28 were not about SPECT or were about SPECT in an area other than myocardial, four were guidelines and recommendations, two were not about COVID-19, two were study protocols, one was in German, and one we were unable to locate the full text of. In the end, 32 records were finally included. In Fig. 1, the study selection process is summarized.

Results

Twelve of the 32 papers included were cross-sectional analytical studies, while four were cross-sectional prevalence studies. Two articles used a retrospective cohort study design, one utilized a historical cohort, and one used a prospective single-arm cohort design. An article was written as a case control. There were also ten case reports and a case series. Based on JBI critical appraisal tools, 21 papers were categorized as high quality, six as medium quality, and five as low quality. In Table 2, all studies that were finally included are listed, along with their study design, publication type, and quality assessment scores.

To present the results in an orderly and classified manner, all finally included records have been organized into one of these three categories:

1) Case reports and case series, which have three sub-categories:
   a) CT-scan findings;
   b) Consideration of motion artifacts;
   c) Complications of COVID-19;
2) Comparison of the number of performed MPIs before and after the pandemic at three levels:
   a) Countries,
   b) Continents,
   c) Global;
3) MPI findings in active or previous COVID-19 patients.

A summary of the results is provided in Table 3. The following explains each category in more detail:

Case reports and case series

Of ten case reports, nine were journal articles, and one was a conference abstract. Of those case reports, six were about computed tomography of the thorax and incidental findings; three were about complications of COVID-19, and one discussed the possibility of motion artifacts when patients wear a mask during MPI SPECT (Table 4).

CT-scan findings

A total of six patients (Table 4, patients one to six), four males and two females, have been examined, ranging in age from 44 to 69. The most common previous cardiovascular disease among them was hypertension. All six patients have been found to have grand glass opacities (GGOs) on their chest CT.

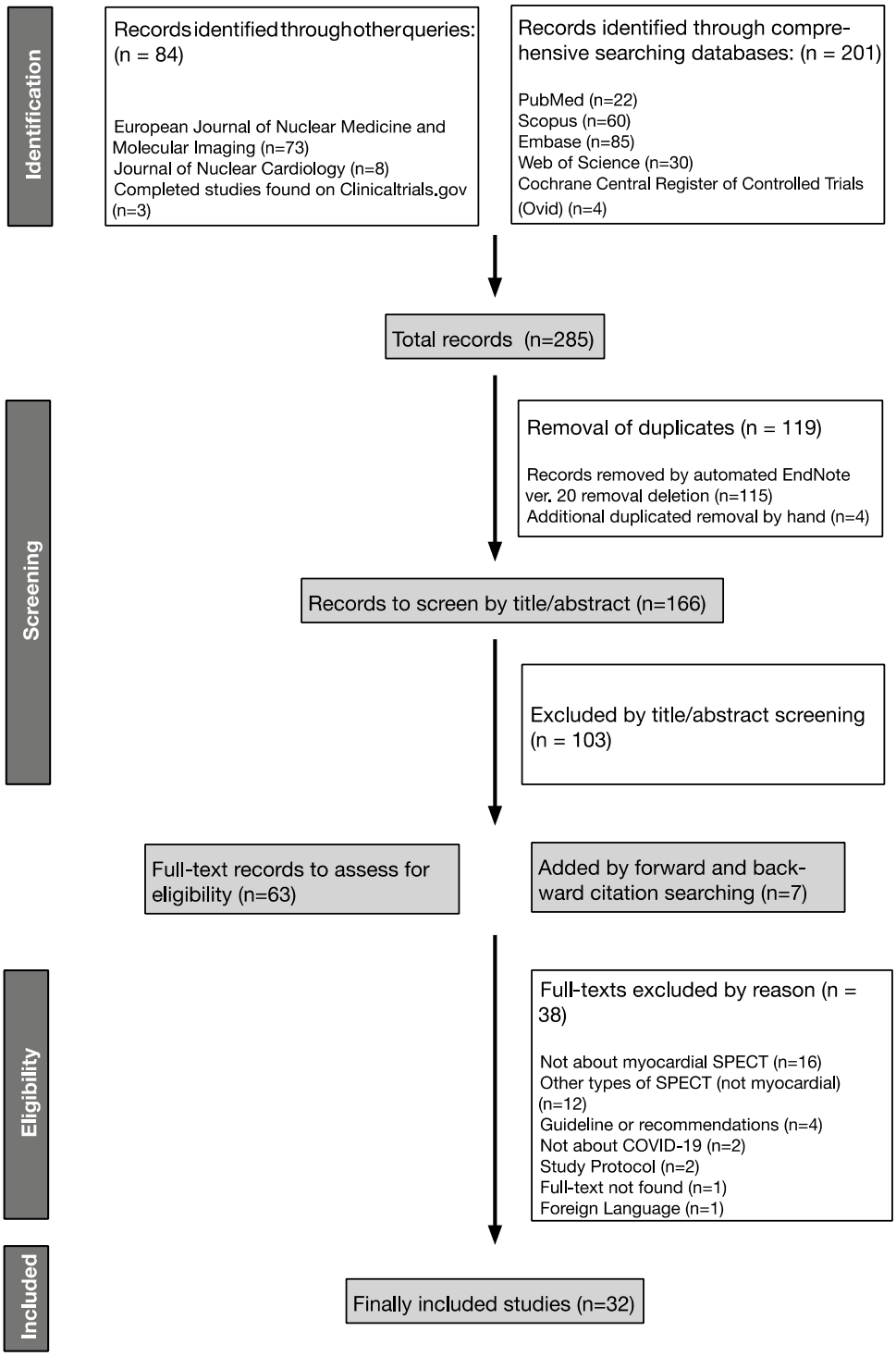


Fig. 1 Prisma flow diagram of study selection

Patients 1 [24] and 3 [25] were referred for exercise SPECT MPI following dyspnea on exertion (DOE), which was reported to be normal. In the CTAC of patient 1, bilateral GGOs were seen in the inferior lobes. A SPECT acquisition quality check was undertaken by reconstructing the thorax of Patient 3, in which both lungs showed high signals. On chest CT, GGOs and crazy-paving patterns were found.

Patients 2 [26] and 4 [27] were referred to MPI for risk assessment before kidney surgery. Patient two had DOE, but his ECG showed no abnormalities, so he underwent MPI for risk stratification before kidney transplant surgery, which revealed stress-induced ischemia without regional septal motion abnormalities and with an LVEF of 66%. Multiple extracardiac uptakes of 99 m-sestamibi were found in CTAC

Table 2 All finally included studies

The first author	Title	Publication type/ Study design	Year	Journal	JBI critical appraisal score	Quality assesses*
Nappi C	Effects of the COVID-19 Pandemic on Myocardial Perfusion Imaging for Ischemic Heart Disease	Analytical cross-sectional, Journal article	2020	European Journal of Nuclear Medicine and Molecular Imaging	8/8	High
Aksu A	Evaluation of Myocardial Perfusion Scintigraphy SPECT and CT Images in Patients with a History of COVID-19	Case–control, Conference abstract	2021	Journal of Nuclear Medicine	4/10	Medium
Assante R	Impact of COVID-19 Infection on Short-Term Outcome in Patients Referred to Stress Myocardial Perfusion Imaging	Retrospective cohort, Journal article	2021	European Journal of Nuclear Medicine and Molecular Imaging	8/11	High
Kudryavtsev A	Molecular Imaging in Diagnosis of Cardiovascular and Lung Damage in Patients with COVID-19	Case series, Conference abstract	2021	European Journal of Nuclear Medicine and Molecular Imaging	4/10	Medium
Salobir G	Myocardial Perfusion Scintigraphy During the COVID-19 Pandemic—Findings from the University Teaching Hospital in Slovenia	Analytical cross-sectional, Conference abstract	2021	European Heart Journal	2/8	Low
Araz M	Myocardial Perfusion SPECT Findings in PostCOVID Period	Historical cohort, Journal article	2021	European Journal of Nuclear Medicine and Molecular Imaging	7/10	High
Hasnie U	Prevalence of Abnormal SPECT Myocardial Perfusion Imaging During the COVID-19 Pandemic	Analytical cross-sectional, Journal article	2021	European Journal of Nuclear Medicine and Molecular Imaging	7/8	High
Kutuk E	Prior COVID-19 History Increases the Risk of Ischemia in Myocardial Perfusion CZT Detectors Scintigraphy	Analytical cross-sectional, Conference abstract	2021	European Journal of Nuclear Medicine and Molecular Imaging	1/8	Low
Scrima G	Safety Measures and Clinical Outcome of Nuclear Cardiology Department During COVID-19 Lockdown Pandemic: Northern Italy Experience	Prospective single-arm cohort, Journal article	2020	Journal of Nuclear Medicine	7/10	Low
Cap M	SPECT Myocardial Perfusion Imaging Identifies Myocardial Ischemia in Patients with a History of COVID-19 Without Coronary Artery Disease	Analytical cross-sectional, Journal Article	2021	The International Journal of Cardiovascular Imaging	8/8	High
Hasnie U	Stress Testing and Myocardial Perfusion Imaging for Patients After Recovery from Severe COVID-19 Infection Requiring Hospitalization: A Single-Center Experience	Retrospective cohort, Journal article/Brief report	2021	Journal of Nuclear Medicine	6/11	Medium
Hindle-Katel W	Incidental Finding of COVID-19 Pulmonary Infiltrates on SPECT/CT Attenuation Correction CT	Case report	2020	Journal of Nuclear Medicine	7/8	High

Table 2 (continued)

The first author	Title	Publication type/ Study design	Year	Journal	JBI critical appraisal score	Quality assesses*
Malek H	Extra-Cardiac Multifocal Lung Uptake of Tc-99 m-Sestamibi in Myocardial Perfusion Imaging: An Asymptomatic Case with Coronavirus Infection Features	Case report	2020	Journal of Nuclear Medicine	5/8	Medium
Delabie P	Increased Lung Signal as a Hint of COVID-19 Infection on Tc-99 m-Sestamibi Myocardial Perfusion Scintigraphy	Case report	2020	Journal of Nuclear Medicine	6/8	High
Ananthasubramaniam K	Lurking in the Shadows: Asymptomatic Bilateral Lung Involvement with Novel Corona Virus 2019 Identified on Myocardial Perfusion SPECT CT: Implications for Interpreting Physicians	Case report	2020	Journal of Nuclear Medicine	8/8	High
Yousefi-Koma A	Multi-Modality Imaging of Inflammation and Ischemia for Assessment of Myocardial Injury in COVID-19	Case report	2020	Journal of Nuclear Medicine	5/8	Medium
Kalantari F	COVID-19 Manifestation on Tl-201 Myocardial Perfusion SPECT/CT	Case report	2021	Iranian Journal of Nuclear Cardiology	8/8	High
Cichocki P	Mask-Related Motion Artifact on 99mTc-MIBI SPECT: Unexpected Pitfalls of SARS-CoV-2 Countermeasures	Case report	2021	Diagnostics	7/8	High
Dondi M	Reduction of Cardiac Imaging Tests During the COVID-19 Pandemic: The Case of Italy. Findings From the IAEA Non-Invasive Cardiology Protocol Survey on COVID-19 (INCAPS COVID)	Analytical cross-sectional, Journal article	2021	International Journal of Cardiology	6/8	High
Freudenberg L	Global Impact of COVID-19 on Nuclear Medicine Departments: An International Survey in April 2020	Prevalence cross-sectional, Journal article	2020	The Journal of Nuclear Medicine	9/9	High
Giammarile F	Changes in the Global Impact of COVID-19 on Nuclear Medicine Departments During 2020: An International Follow-Up Survey	Prevalence cross-sectional, Journal article	2021	European Journal of Nuclear Medicine and Molecular Imaging	9/9	High
Giammarile F	Impact of COVID-19 on Nuclear Medicine Departments in Africa and Latin America	Prevalence cross-sectional, Journal article	2021	Seminars in Nuclear Medicine	9/9	High
Hirschfeld C	Impact of COVID-19 on Cardiovascular Testing in the United States Versus the Rest of the World	Analytical cross-sectional, Journal article	2021	JACC: Cardiovascular Imaging	8/8	High
Einstein A	International Impact of COVID-19 on the Diagnosis of Heart Disease	Analytical cross-sectional, Journal article	2021	Journal of the American College of Cardiology	8/8	High

Table 2 (continued)

The first author	Title	Publication type/ Study design	Year	Journal	JBI critical appraisal score	Quality assesses*
O'Sullivan P	Impact of COVID-19 on Diagnosis Cardiac Procedural Volume in Oceania: The IAEA Non-Invasive Cardiology Protocol Survey on COVID-19 (INCAPS COVID)	Analytical cross-sectional, Journal article	2021	Heart, Lung and Circulation	8/8	High
Williams C	Impact of COVID-19 on the Imaging Diagnosis of Cardiac Disease in Europe	Analytical cross-sectional, Journal article	2021	Open Heart	8/8	High
Skali H	Clinical and Economic Outcomes of Pharmacological Stress Tests in Patients with a History of COVID-19	Analytical cross-sectional, Conference abstract	2022	Journal of the American College of Cardiology	2/8	Low
Bilge O	The Effect of Coronavirus Disease 2019 Pneumonia on Myocardial Ischemia Detected by Single-Photon Emission Computed Tomography Myocardial Perfusion Imaging	Analytical cross-sectional, Journal article	2022	Nuclear Medicine Communications	8/8	High
Koo B.S	Mild or Asymptomatic COVID-19 Infection Is Associated with a High Likelihood of SPECT Myocardial Perfusion Abnormalities Even in the Absence of Obstructive Coronary Artery Disease	Prevalence cross-sectional, Conference abstract	2022	Journal of the American College of Cardiology	7/9	High
Osorio Martinez A	SARS-CoV-2-Related Subacute Thyroiditis, Myocarditis, and Hepatitis After Full Resolution of COVID-19 Serum Markers	Case report	2021	American Journal of Case Reports	8/8	High
Emren Z.Y	Spontaneous Right Coronary Artery Dissection in a Patient With COVID-19 Infection: A Case Report and Review of the Literature	Case report	2021	Turk Kardiyologi Dernegi Arsivi	4/8	Medium
Kunnirickal S	Symptomatic Coronary Endothelial Dysfunction After Recovery From COVID-19	Case report, Conference abstract	2021	Journal of the American College of Cardiology	3/8	Low

*For ease of comparison, this column's calculation is based on the results of the JBI critical checklist. Scores below 1/3 are deemed to be of low quality, those between one-third and two-thirds are considered to be of medium quality, and scores above two-thirds are judged to be of high quality

Table 3 Summary of findings

Category	Scope	The first author	Title	Are of study	Takeaway	Quality assessed
Comparing the numbers of performed SPECT MPIs before and after the pandemic	Countries	Nappi C	Effects of the COVID-19 Pandemic on Myocardial Perfusion Imaging for Ischemic Heart Disease	Italy	Significant reduction of performed MPIs	High
		Salobir G	Myocardial Perfusion Scintigraphy During the COVID-19 Pandemic—Findings from the University Teaching Hospital in Slovenia	Slovenia	MPI numbers reduction in the first wave of COVID-19, which got back to normal in the second wave following reorganizing their schedule	Low
		Hasnie U	Stress Testing and Myocardial Perfusion Imaging for Patients After Recovery from Severe COVID-19 Infection Requiring Hospitalization: A Single-Center Experience	USA	Significant reduction of performed MPIs	Medium
		Kutuk E.S	Prior COVID-19 History Increases the Risk of Ischemia in Myocardial Perfusion CZT Detectors Scintigraphy	Turkey	Significant reduction of performed MPIs	Low
	Countries versus the rest of the world	Dondi M	Reduction of Cardiac Imaging Tests During the COVID-19 Pandemic: The Case of Italy. Findings From the IAEA Non-Invasive Cardiology Protocol Survey on COVID-19 (INCAPS COVID)	Italy vs. RoW and RoE	MPI numbers reduction in Italy was more prominent compared to the RoW and RoE	High
		Hirschfeld C	Impact of COVID-19 on Cardiovascular Testing in the United States Versus the Rest of the World	USA vs. RoW	Reduction in performed MPIs was similar between the U.S and non-U.S. facilities	High
	Continents	Giammarile F	Impact of COVID-19 on Nuclear Medicine Departments in Africa and Latin America	Africa, and Latin America	Significant reduction of performed MPIs	High
		O'Sullivan P	Impact of COVID-19 on Diagnosis Cardiac Procedural Volume in Oceania: The IAEA Non-Invasive Cardiology Protocol Survey on COVID-19 (INCAPS COVID)	Oceania	Considerable reduction in performed MPIs, which was less than the global decrease	High
		Williams C	Impact of COVID-19 on the Imaging Diagnosis of Cardiac Disease in Europe	Europe	MPIs numbers reduction, which was more than RoW	High

Table 3 (continued)

Category	Scope	The first author	Title	Are of study	Takeaway	Quality assessed
	Worldwide	Freudenberg L	Global Impact of COVID-19 on Nuclear Medicine Departments: An International Survey in April 2020	Global	Significant reduction of performed MPIs	High
		Giammarile F	Changes in the Global Impact of COVID-19 on Nuclear Medicine Departments During 2020: An International Follow-Up Survey	Global	Significant reduction of performed MPIs	High
		Einstein A	International Impact of COVID-19 on the Diagnosis of Heart Disease	Global	Significant reduction of performed MPIs	High
SPECT MPI findings		Assante R	Impact of COVID-19 Infection on Short-Term Outcome in Patients Referred to Stress Myocardial Perfusion Imaging	Italy	COVID-19 and abnormal MPI both increased cardiac event risk	High
		Araz M	Myocardial Perfusion SPECT Findings in PostCOVID Period	Turkey	The frequency of ischemia on MPI is much higher in patients with a history of COVID-19	High
		Cap M	SPECT Myocardial Perfusion Imaging Identifies Myocardial Ischemia in Patients with a History of COVID-19 Without Coronary Artery Disease	Turkey	SARS-CoV-2 infection could predict abnormal MPI	High
		Hasnie U	Prevalence of Abnormal SPECT Myocardial Perfusion Imaging During the COVID-19 Pandemic	USA	The number of patients with MPI testing after COVID-19 infection will increase over time	High
		Bilge O	The Effect of Coronavirus Disease 2019 Pneumonia on Myocardial Ischemia Detected by Single-Photon Emission Computed Tomography Myocardial Perfusion Imaging	Turkey	COVID-19 pneumonia could predict ischemia on SPECT-MPI	High

Table 3 (continued)

Category	Scope	The first author	Title	Are of study	Takeaway	Quality assessed
		Koo B.S	Mild or Asymptomatic COVID-19 Infection Is Associated with a High Likelihood of SPECT Myocardial Perfusion Abnormalities Even in the Absence of Obstructive Coronary Artery Disease	USA	Prior SARS-CoV-2 infection ais associated with SPECT MPI defects	High
		Aksu A	Evaluation of Myocardial Perfusion Scintigraphy SPECT and CT Images in Patients with a History of COVID-19	Turkey	Even during COVID patients' improvement interval, radiopharmaceutical uptake may be observed	Medium
Case reports and case-series		Hindle-Katel W	Incidental Finding of COVID-19 Pulmonary Infiltrates on SPECT/CT Attenuation Correction CT	USA	Importance of performing and reviewing CATC alongside SPCET MPI imaging during the pandemic	High
		Malek H	Extra-Cardiac Multifocal Lung Uptake of Tc-99 m-Sestamibi in Myocardial Perfusion Imaging: An Asymptomatic Case with Coronavirus Infection Features	Iran	Importance of performing CATC alongside SPCET MPI imaging during the pandemic	Medium
		Delabie P	Increased Lung Signal as a Hint of COVID-19 Infection on Tc-99 m-Sestamibi Myocardial Perfusion Scintigraphy	France	Importance of performing and reviewing CATC alongside SPCET MPI imaging during the pandemic	High
		Ananthasubramaniam K	Lurking in the Shadows: Asymptomatic Bilateral Lung Involvement with Novel Corona Virus 2019 Identified on Myocardial Perfusion SPECT CT: Implications for Interpreting Physicians	USA	Importance of performing and reviewing CATC alongside SPCET MPI imaging during the pandemic	High
		Yousefi-Koma A	Multi-Modality Imaging of Inflammation and Ischemia for Assessment of Myocardial Injury in COVID-19	Iran	The acute inflammatory response precipitated by COVID might account for the perfusion defect in the rest SPECT	Medium
		Kalantari F	COVID-19 Manifestation on Tl-201 Myocardial Perfusion SPECT/CT	Iran	Importance of performing and reviewing CATC alongside SPCET MPI imaging during the pandemic	High

Table 3 (continued)

Category	Scope	The first author	Title	Are of study	Takeaway	Quality assessed
		Cichocki P	Mask-Related Motion Artifact on 99mTc-MIBI SPECT: Unexpected Pitfalls of SARS-CoV-2 Countermeasures	Poland	Mask-related motion artifacts can create false-positive MPS results	High
		Osorio Martinez A	SARS-CoV-2-Related Subacute Thyroiditis, Myocarditis, and Hepatitis After Full Resolution of COVID-19 Serum Markers	Mexico	When facing patients with cardiovascular symptoms, we should keep COVID and its complication in the post-COVID period in mind	High
		Emren Z.Y	Spontaneous Right Coronary Artery Dissection in a Patient With COVID-19 Infection: A Case Report and Review of the Literature	Turkey	Spontaneous coronary artery dissection may develop as a COVID-19 complication	Medium
		Kunnirickal S	Symptomatic Coronary Endothelial Dysfunction After Recovery From COVID-19	USA	Some patients may experience endothelial dysfunction and smooth muscles hyperreactivity in the post-COVID period	Low
		Kudryavtsev A	Molecular Imaging in Diagnosis of Cardiovascular and Lung Damage in Patients with COVID-19	Russia	COVID-19 may cause false-positive results on myocardial SPECT/CT	Medium
Other		Scrima G	Safety Measures and Clinical Outcome of Nuclear Cardiology Department During COVID-19 Lockdown Pandemic: Northern Italy Experience	Italy	The importance and necessity of implementing the published guidelines and best-practices	Low
		Skali H	Clinical and Economic Outcomes of Pharmacological Stress Tests in Patients with a History of COVID-19	USA	Patients with a history of SARS-CoV-2 infection a year before performing pharmacological stress MPI were more likely to incorporate a reversal agent	Low

Table 4 Case reports and case series

Article type	The first author	Patient no	Country	Gender, age	Reason of referral	MPI cardiac findings	Pulmonary findings	Covid Diagnosis	Conclusion
Case report	Hindle-Katel W	1	USA	Male, 65	Clinical suspicious for CAD	Normal	Abnormal pulmonary GGOs in the bilateral lower lobes in CATC	COVID test was positive (doesn't specify the test technique)	With CTAC, it became possible to discover that he had COVID (as an incidental finding). That's why non-cardiac findings are also important in MPI/CTAC
	Malek H	2	Iran	Male, 44	Preoperative risk stratification, had DOE without chest pain	Stress-induced apical ischemia, LVEF = 60%	Multifocal abnormal uptake in both lungs, corresponding to the CTAC GGOs	CT images showed multiple peripherally distributed GGOs, typical of COVID lung involvement. The patient wasn't tested right away, but was quarantined	In regions where the disease has spread extensively, 99 m-Tc-sestamibi uptake in lungs could be considered a feature of pulmonary infection with COVID-19. Identifying and diagnosing COVID can be made easier with CTAC
	Delabie	3	France	Male, 50	Has Had DOE since a month prior	Normal	In both lungs, high signals observed during thorax reconstruction for quality check. Following that, a chest CT revealed GGOs and crazy paving pattern	Positive rtPCR	The high lung signal can indicate an asymptomatic COVID-19 infection, especially in a normal LVEF. Also, as per ASNC, nuclear cardiology centers should be organized to identify symptoms of active COVID and prevent stress testing in patients showing them

Table 4 (continued)

Article type	The first author	Patient no	Country	Gender, age	Reason of referral	MPI cardiac findings	Pulmonary findings	Covid Diagnosis	Conclusion
	Ananthasubramaniam K	4	USA	Male, 47	Risk assessment prior to be listed for kidney transplant	Mild perfusion defect, and CTAC showed three vessel coronary calcification	Peripheral GGOs in both lungs in CTAC	Positive rtPCR	COVID can hide in the shadows. Even though he had a bilateral involvement, the patient was asymptomatic. It reminds us of the importance of reviewing CTACs, where there are sometimes critical non-cardiac findings hidden
	Yousefi-Koma A	5	Iran	Female, 69	Dyspnea and chest pain. LBBB in ECG. Echocardiography showed hypokinesis	Rest perfusion defects	Bilateral GGOs in chest CT	Positive rtPCR	The acute inflammatory response precipitated by COVID might account for the perfusion defect in the rest SPECT, although this is characteristics of myocarditis. CT images revealed the COVID infection in this case
	Kalantari F	6	Iran	Female, 67	Assessment of IHD	Normal	Multifocal, bilateral, and peripheral GGOs in lungs, accompanied with fine background uptake of TI-201	According to the chest CT and considering the outbreak, the initial diagnosis was COVID. The patient was recommended to undergo a test, but she declined	This case emphasizes the importance of non-cardiac findings in patients who undergo SPECT CT. Also, CTAC should be interpreted in the context of COVID. Before discharge, these images should be interpreted

Table 4 (continued)

Article type	The first author	Patient no	Country	Gender, age	Reason of referral	MPI cardiac findings	Pulmonary findings	Covid Diagnosis	Conclusion
	Cichocki P	7	Poland	Male, 61	To exclude CAD	Initial rest MPI showed a mild perfusion defect, and stress imaging showed stress-induced ischemia. The test was repeated because the result was inconsistent with the patient's good condition, and the patient stated that his mask was in a bad position. The second stress image showed stress-induced ischemia. The only finding was a mild perfusion defect in the apex and inferoseptal wall of LV (which is common in LBBB)			Mask-related motion artifacts can create false-positive MPS results (especially stress) that can lead to invasive procedures for the patient. This case report reminds us of the prominent role of technologists and the importance of matching the patient's bedside with test results
	Osorio Martinez A	8	Mexico	Male, 64	Oppressive chest pain began three weeks after the COVID	Normal	GGOs in chest CT	Positive rtPCR	This case is about some possible complications after COVID. Some post-COVID patients might experience myocarditis. We should keep COVID and its complication in the post-COVID period in mind
	Emren Z.Y	9	Turkey	Male, 50	To rule out infarction and ischemia, seven days after COVID diagnosis	Myocardial ischemia in the inferior and posterior segments		Positive rtPCR	This case is about another possible complications of COVID, Spontaneous coronary artery dissection

Table 4 (continued)

Article type	The first author	Patient no	Country	Gender, age	Reason of referral	MPI cardiac findings	Pulmonary findings	Covid Diagnosis	Conclusion
	Kunnirickal S	10	USA	Male, 65	Shortness of breath and DOE, with a history of COVID infection and intubation three months ago	Chest pain during exercise MPI, with a minor apical anterior and septal defect			Some patients may experience endothelial dysfunction and smooth muscles hyperreactivity in the post-COVID period. This case emphasizes the importance of physiological and provocative testing in this population
Case series	Kudryavtsev A	11–20	Russia	6 male, 4 female. 55 to 75 years old		Among 10, seven patients had an increased LHR (mean 0.62, SD 0.1)			COVID-19 may cause false-positive results on myocardial SPECT/CT in patients with the disease due to increase uptake in pulmonary tissue as well as an increase in the LHR. An FDG PET/CT might be clinically helpful in gathering information about the inflammatory process in the lung parenchyma

with GGOs. Detection of the SARS-CoV-2 infection in patient two is an incidental finding following CT scanning, as it was for patients 1 and 3. This case report argues that a multi-focal increase in 99-m-sestamibi uptake may indicate SARS-CoV-2 infection.

Patient 4 had no general or cardiac symptoms and was referred to MPI for kidney transplant risk assessment. On the MPI, there was mild ischemia along with bilateral GGOs in the CATC, which was interpreted as COVID-19 lung involvement. Patient 2 and 4 CTACs showed SARS-CoV-2 infection involvement as incidental findings. Both authors of the above two case reports concluded that if multi-focal high uptake of sestamibi is reported, COVID-19 may be considered a differential diagnosis since COVID can hide in the shadows.

Patients 5 [28] and 6 [29] also suggest that we should reconsider our diagnostic approach in the context of the COVID-19 pandemic when we must pay attention to both the probable COVIDIAn nature of our patients and the importance of noncardiac findings. Both CATC and MPI of patients should be interpreted in terms of the likelihood of SARS-CoV-2 infection and done upon discharge.

Kudryavtsev et al. case series [30] findings are in accordance with patient 5. Ten patients with moderate COVID-19 in this case series underwent PET/CT with FDG and SPECT/CT with 99-m-to-mibi. Because of inflammatory changes in lung tissue, seven of the ten had an increased lung-to-heart ratio (LHR). In this case series, presented as a conference abstract, Kudryavtsev and colleagues reported that these changes may look like CAD, where usually diffuse myocardial hypo-perfusion can be the reason for increased LHR. However, myocardial PET/CT did not show any significant FDG uptake, and the greatest increase in uptake of FGF has occurred in areas with GGO involvement and mediastinal lymph nodes. Consolidations, on the other hand, have shown less uptake of FDG. As Kudryavtsev et al. concluded, myocardial SPECT in COVID-19 patients may lead to false-positive diagnoses of coronary artery disease (CAD) because of increased pulmonary tissue uptake and LHR increase; in these instances, FDG PET/CT could provide valuable information regarding inflammation within the lung parenchyma.

Consideration of motion artifacts

An occupational physician referred patient 7 [31] for the exclusion of CAD. On his initial electrocardiogram, LBBB was detected. He underwent rest MPI, which showed a mild perfusion defect in the inferoseptal wall and left ventricle apex. The patient then underwent stress MPI, which revealed multiple significant stress-induced ischemias. Since this finding did not align with the patient's good health, a nuclear medicine technician performed a quality control test, revealing that his heart was moving along the *Z* axis throughout the imaging.

Additionally, the patient claimed that his mask had slipped into an uncomfortable position and caused him to experience breathing difficulties. After a second stress test was conducted on him, he had nothing but a fixed perfusion defect at the apex and inferoseptal wall, which is common in patients with LBBB. According to the case study, many patients use a mask during nuclear imaging during the pandemic period, which can lead to false-positive results during MPIs. So, nuclear medicine technologists should pay attention to these possible artifacts. Additionally, if the stress or rest imaging results were not in accordance with the patient's clinical condition, additional data processing is required.

Complications of COVID-19

In the last three patients (8, 9, and 10), SPECT MPI was performed to diagnose complications associated with COVID-19. It has been reported that COVID may cause three possible complications since the pandemic's beginning. These include myocarditis in patient 8 [32], spontaneous coronary artery dissection in patient 9 [33], and post-COVID endothelial dysfunction in patient 10 [34]. As a result of the authors' reports in these three studies, they assert that physicians should keep an eye out for cardiac and noncardiac complications that could result from SARS-CoV-2 infection.

Comparing the number of MPIs before and after the pandemic

Two of the 12 articles that compared the number of MPI SPECTs conducted before and after the pandemic were conference abstracts. The remaining nine were journal articles. As shown in Table 5, four of those 12 records dealt with a specific country (the United States, Turkey, Slovenia, and Italy), three focused on continents, and five were global (two were specific to a country versus the rest of the world). According to all of these studies, the number of SPECT MPIs performed following the pandemic was lower than before.

The comparison of countries

Nappi et al. conducted a comparison of stress SPECT MPIs performed at the Napoli Federico II center, Italy, between February and May 2020 with those performed at the same time in 2017, 2018, and 2019 [35]. The number of SPECT MPI during the pandemic was lower than the average for the preceding three years ($P < 0.0001$). It has been reported that in those months of 2020, approximately 36% of stress MPIs were abnormal, similar to the corresponding month of the previous three years ($P = 0.65$). Despite the fact that they had

Table 5 Comparing the numbers of performed SPECT MPIs before and after the pandemic

	The first author	Area of study	Location/Source	Imaging technique	Comparing pre and post pandemic	Interpretation
Reduction in Countries	Nappi C	Italy	University of Napoli Federico II	Stress SPECT MPI	*post-pandemic:* Between February and May 2020: 123 *pre-pandemic:* Between February and May 2019: 418 Between February and May 2018: 415 Between February and May 2017: 413	The number of procedures during the pandemic was significantly lower ($P < 0.0001$)
	Salobir G	Slovenia	University Medical center Ljubljana	SPECT MPI	*post-pandemic:* Spring 2020 (the first wave): 233 Autumn 2020 (the second wave): 347 *pre-pandemic:* Spring 2019: 366 Autumn 2019: 349	During the first wave of the pandemic, they performed 40% fewer MPI They reorganized their schedule for COVID's second wave patient numbers, which were once again comparable to last autumn
	Hasnie U	USA	University of Alabama Medical Center at Birmingham	SPECT MPI	*post-pandemic:* 2020, per month: 105 *pre-pandemic:* 2019, per month: 553	When the pandemic restrictions were at their peak, SPECT MPI studies were significantly reduced
	Kutuk E.S	Turkey	Ankara City Hospital	SPECT MPI	*post-pandemic:* August to November, 2020: 896 *post-pandemic:* August to November, 2019: 1415	There was a significantly lower number of procedures during the pandemic ($P < 0.01$)

Table 5 (continued)

	The first author	Area of study	Location/Source	Imaging technique	Comparing pre and post pandemic	Interpretation
Reduction in a Country Versus the Rest of the World	Dondi M	Italy vs. RoW and RoE	52 Italian centers, and 909 centers from 198 countries	Stress SPECT MPI	*Reduction of Stress SPECT in March 2020 compared to March 2019:* Italy: 66% Rest of the world: 39% Rest of Europe: 46% ($P < 0.001$) *Reduction of Stress SPECT in April 2020 compared to March 2019:* Italy: 84% Rest of the world: 73% Rest of Europe: 78% ($P = 0.006$)	There was a significant reduction of performed MPIs in Italy, which was more prominent compared to the rest of the world and the rest of Europe
	Hirschfeld C	USA vs. RoW	INCAPS COVID	Stress SPECT MPI	*Reduction in the U.S in April 2020 compared to March 2019:* 75% *Reductions by U.S. regions:* *Midwest: 77%,* *Northeast: 87%* *South: 68%* *West: 47%* *Reduction in other countries in April 2020 compared to March 2019:* 74%	Early COVID-19 pandemic reductions in cardiovascular testing were similar between the U.S. and non-U.S. facilities. However, the Northeast and Midwest regions in the U.S experienced the greatest reductions in procedure volumes
Reduction in Continents	Giammarile F	Africa, and Latin America	Web based questionnaire, through a software hosted by IAEA	SPECT MPI	Africa: *in June 2020:* of 23, 70% of centers reported a reduction, 26% standstill *in October 2020:* of 23, 52% of centers reported a reduction, 13% standstill Latin America: *in June 2020:* of 61, 85% of centers reported a reduction, 16% standstill *in October 2020:* of 62, 79% of centers reported a reduction, 8% standstill	As a result of pandemic-related challenges, nuclear medicine diagnostics and therapeutics decreased in 2020. A more significant negative impact is felt in low- or middle-income countries like Africa and Latin America. Compared to October, when the situation improved, the decline in June was greater. But still, the number of procedures conducted was lower than pre-pandemic

Table 5 (continued)

	The first author	Area of study	Location/Source	Imaging technique	Comparing pre and post pandemic	Interpretation
	O'Sullivan P	Oceania	INCAPS COVID	Stress SPECT MPI	*Reduction of tests comparing March 2019 to April 2020:* 44.3% *Reduction by type of centers*:* *In metropolitan sites: 41%* *In regional sites: 48%* *In public sites: 43%* *In private sites: 47%* *In hospitals: 45%* *In outpatient sites: 43%* *Teaching centers: 42%* *Non-teaching centers: 52%* **No significant reduction among none of them in the comparison*	Oceania has had a considerable decrease, which, of course, was less than the global decrease
	Williams C	Europe	INCAPS COIVD	Stress SPECT MPI	*Reduction of tests comparing March 2019 to April 2020:* Europe: 79% RoW: 73% *Reduction by European region:* *Western: 73%* *Southern: 83%* *Eastern: 76%* *Northern: 77%*	Comparing the reduction of Europe to the rest of the world, the decline was more significant in Europe ($P=0.002$), but there are no significant differences between various regions of Europe ($P=0.112$)
Worldwide Reduction	Freudenberg L	Global	Web based questionnaire, through a software hosted by IAEA	SPECT MPI	66% reduction reported in SPECT MPI studies *(Questionnaires made available online from April 16th to May 3rd, 2020)*	This study shows a worldwide decline in SPECT MPI imaging centers' activity during the COVID-19 pandemic
	Giammarile F	Global	Web based questionnaire, through a software hosted by IAEA	SPECT MPI	*In June 2020:* of 244 centers, 79.5% reported a reduction *In October 2020:* of 244 centers, 64.3% reported a reduction *(Questionnaires made available online from November 23rd to 31st December, 2020)*	This study is a follow-up to the previous survey (Upper row, by Freudenberg L. et. Al). Again, it shows the reduction of nuclear medicine's diagnostic and therapeutic services worldwide

Table 5 (continued)

	The first author	Area of study	Location/Source	Imaging technique	Comparing pre and post pandemic	Interpretation
	Einstein A	Global	INCAPS COVID	Stress SPECT MPI	*Worldwide reduction comparing March 2019 to March 2020:* 42% *Worldwide reduction comparing March 2019 to April 2020:* 74% *Reduction from March 2019 to April 2020 by type of center:* *Reduction by type of facility:* *Hospital inpatient only: 72%* *Hospital inpatient and outpatient: 75%* *Hospital outpatient only: 71%* *Outpatient imaging Center: 77%* *Outpatient physician practice: 69%* *Reduction by teaching center status:* *Teaching: 75%* *Non-teaching: 73%* *Reduction by hospital beds:* *Lowest tertile: 81%* *Middle tertile: 78%* *Highest tertile: 70%* *All non-urgent outpatient procedures reductions:* *Not canceled: 72%* *Canceled: 78%*	During the COVID-19 pandemic, the activity of SPECT MPI imaging centers decreased worldwide

an average of 319 abnormal stress MPIs in the 3 years prior to the pandemic, it dropped to 44 abnormal tests during the pandemic, so Nappi et al. concluded that approximately 68% were missing. According to the study cohort's demographics, many were elderly, had hypertension, or were diabetic.

At the University Medical Center Ljubljana in Slovenia, Salobir and colleagues compared MPIs carried out during two periods of the epidemic with those before the outbreak [36]. By spring 2019, during the first wave of the COVID-19 pandemic, the number of MPIs had been reduced to 40%, whereas by autumn 2020, the second wave, the number of MPIs had risen to almost as high as before the pandemic even started. Salobir et al. in that center reset their schedule planning and restored the number of MPIs to the level before the pandemic. Due to the possibility of SARS-CoV-2 virus transmission from asymptomatic patients, they have attempted to follow international community recommendations and increased the number of pharmacological stress MPI tests instead of stress tests. They continued with this approach until the second wave, but they then decided to increase the number of MPIs to reduce the negative impact of the COVID-19 pandemic on non-COVID patients, especially those with coronary artery disease (CAD).

Hasnie et al. at the University of Alabama Medical Center in Birmingham, USA, compared the mean number of MPIs performed in 2020 with the mean number performed in 2019, which revealed an 81% decrease [37]. The number of abnormal SPECT MPIs was 31% in 2020 and 27% in 2019. The proportion of abnormal SPECT MPIs did not significantly change between the 2 years ($P = 0.4$). Based on the same calculation as Nappi et al. [35], Hasnie and colleagues found that about 81% of abnormal studies were missed during the COVID-19 pandemic.

Kutuk et al. from Turkey compared the amount of MPI between August and November of 2020 to the same period in 2019 and found that SPECT MPIs in 2020 were significantly lower than in 2019 ($P < 0.01$) [38]. At the same time, the ischemic MPI rate in 2020 was higher than before the pandemic (42.2 versus 31.0%, $P < 0.01$). In the pandemic group, patients with a history of SARS-CoV-2 infection had a higher rate of ischemic MPIs than those without (52.4 versus 41.1%, $P = 0.049$). Therefore, they ultimately concluded that an individual with a history of SARS-CoV-2 infection was 1.5 times more likely to have ischemic MPI results (OR = 1.57, 95%CI, 1.003–2.470, $P = 0.048$). According to the study conducted by Kutuk and colleagues, infection with COVID-19 may lead to an increased risk of ischemia in patients undergoing SPECT MPI.

Continent comparison

The International Atomic Energy Agency (IAEA) conducted a survey in April 2020 in order to determine the initial impact of the COVID-19 pandemic on nuclear medicine facilities worldwide [39]. They conducted a follow-up study to further investigate the matter in October 2020 and June 2020 [40]. The Giammarile et al. study highlights that follow-up in Africa and Latin America [41]. The IAEA provided an online questionnaire powered by IAEA software for 6 weeks, from November 23 to December 31, 2020. In June 2020, 71% of 23 centers reported having lower MPI than pre-pandemic, and 26% of those centers had halted operations entirely. By October 2020, 52% of centers reported doing less MPI than before the pandemic, and 13% of centers were at a complete standstill.

According to the paper by Giammarile and colleagues, of 61 centers in Latin America in June 2020, 85% performed less MPI than before COVID, and 16% of the centers ceased to operate. In October 2020, of 62 centers in Latin America, 70% of centers reported having less SPECT MPI than before the pandemic, and 8% of facilities stopped working.

This study was conducted to examine the impact of the COVID-19 pandemic on nuclear medicine services in lower-middle-income countries. It was revealed that a significant decrease in nuclear medicine facilities' activities had occurred in Africa and Latin America due to the pandemic. Compared to October of the same year, the decline was more pronounced in June 2020, and between the two regions, it was more severe in South America.

The non-invasive cardiology protocol survey on COVID (INCAPS COVID) was designed and carried out by the IAEA division of human health. Previously, the IAEA conducted numerous studies on cardiac nuclear imaging, including INCAPS-1, an international multi-center investigation into nuclear imaging activities [42]. INCAPS COVID was an international multi-center investigation designed to assess the impact of the COVID-19 pandemic on nuclear medicine imaging facilities [43]. INCAPS provided web-based questionnaires, and the International Research Integration System (iris.iaea.org) collected the data. These surveys included questions about health facilities, medical staff, personal protective equipment, plans for reopening centers damaged by the pandemic, and variations in the number of cardiac imaging procedures—like SPECT MPI—during the COVID-19 pandemic. These online questionnaires did not collect any personal information about the patients [44]. In addition to reviewing data obtained from facilities, the Data Coordination Committee dealt with mixed, duplicate, and inconsistent data. Ultimately, only one data set from each facility was used in the final analysis [45]. A total of 27 of the 936 questionnaires submitted for this survey were excluded, resulting in data collected from 909 centers in 198 countries [46]. In various papers that used INCAPS COVID data, the statistics of March and April 2020 have been compared with March 2019 as a basis for comparison.

O'Sullivan et al. outlined INCAPS COVID data from 63 Oceania centers (including New Zealand, Australia, and Papua New Guinea) [44]. From March 2019 to April 2020, the number of stress SPECT MPIs conducted in Oceania decreased by 44.3%. During the research, the disparities among different facilities were also analyzed. In metropolitan areas, the decrease from March 2019 to April 2020 was 41%, whereas, in regional centers, it was 48%. There was a 43% reduction in public sites, while a 47% reduction was observed in private sites. In hospitals, the decrease was about 45%, while in outpatient facilities, it was 43%. The reduction in teaching and non-teaching centers was 42 and 52%, respectively. Significant reductions were not reported in either category.

As reported by O'Sullivan and colleagues, cardiac nuclear facilities' activities in Oceania and the rest of the world (RoE) have decreased, although the reduction in Oceania was relatively more minor. The authors of this article speculated that part of this reduction was possibly due to recommendations of nuclear imaging associations and legislative action taken by governments to reduce the spread of COVID-19. According to their conclusion, allocating resources to COVID should not result in the neglect of cardiovascular diseases, particularly since COVID can last for months or even years. Finally, the authors argued that this pandemic gave us a unique opportunity to reevaluate our healthcare systems from genesis. By doing this, we will be able to make a significant impact and improve our resource allocation mechanisms.

INCAPS COVID findings on Europe were outlined by William et al. [45]. As compared to March 2019, the number of stress SPECT performed dropped by 79%, which is a significant decrease compared to a reduction of 73% from RoW ($P=0.002$). They also assessed reductions in different regions of Europe: decreases in western, southern, eastern, and northern regions were 73, 83, 76, and 77%, respectively. Different parts of Europe showed no significant differences ($P=0.112$).

Global

In two stages, an Internet questionnaire was sent to nuclear medicine facilities worldwide following the outbreak of COVID-19 through software hosted by the IAEA.

The first stage was conducted between April 16 and May 3, 2020, and 434 responses were received from 72 countries. Freudenberg et al. noted in their paper that there was a 66% reduction in the number of SPECT MPIs performed globally [39].

The study of Giammarile and colleagues focused on the second phase, the first phase follow-up, in which questionnaires were available online for 6 weeks between November 23 and December 31 [40]. Of 505 respondents from 96 countries, data were extracted from 355 questionnaires. Among these, 338 questionnaires were fully completed. According to the prescribed survey, 79.5% of the 244 centers in June 2020 and 64.3% in October 2020 performed fewer MPIs. Throughout the world, nuclear medicine diagnostic and treatment services have declined, as described in this follow-up study by Giammarile et al. This decline was more pronounced in June 2020 than in October 2020. Compared to April 2020, the June 2020 nuclear medicine diagnostic and treatment services number was considerably lower, but not significantly different in the SPECT MPI area. Nevertheless, compared to before the pandemic, these services have decreased by more than 50%.

In Einstein and associates' paper, studies related to the INCAPS COVID executive committee survey are discussed, which included 909 centers from 108 countries [43]. Compared to March 2019, the worldwide reduction in stress SPECT was 42% in March and 74% in April 2020. Considering the differences among the types of centers, the reduction of various centers is also discussed. According to the type of facility, hospitals saw a 71% reduction, outpatient centers saw a 77% decline, and outpatient physician practices saw a 69% decrease. Based on teaching statutes, teaching centers had a 75% reduction, and non-teaching centers had a 73% reduction. According to the number of beds, the stress SPECT decreased 81% in the lowest tertile, 78% in the middle tertile, and 70% in the highest tertile. They conclude that the activity of nuclear medicine facilities worldwide declined following the pandemic's beginning. The study suggests the need to plan for future pandemics by providing better access to cardiac diagnostic services worldwide, especially in low- and middle-income countries.

Among the five studies examining the decline of SPECT MPIs globally, two evaluated a particular country compared to the RoW (Table 5).

In a study using results from the IAEA survey, Dondi and colleagues assessed cardiac imaging tests performed in 52 Italian cardiac centers during the pandemic against 909 centers in 108 countries, as well as in other European countries [47].

In March 2020, stress SPECT tests decreased by 66% in Italy, compared to the rest of the world (RoW) and the rest of Europe (RoE), where reduction rates were 39% and 46%, respectively; this indicates that the Italian decrease was significant in comparison to those in RoW and RoE ($P<001$). As stated by the authors of this study, in March and April 2020, the Italian health system faced unprecedented pressure due to the spread of COVID-19. Thus, the delivery of routine services was delayed, resulting in a decrease in the number of cardiac imaging procedures in Italy. They conclude that, given the vital importance of cardiac imaging in public health programs, departments in Italy and across the world should be prepared to provide medical services

in critical conditions to patients and non-patients without endangering clinical staff.

Using data from INCAPS COVID, Hirschfeld et al. compared the United States with the rest of the world [48]. The number of stress SPECTs performed decreased by 75% in April 2020 compared to March of that year in the United States, a decrease that was not statistically significant from the decrease observed in non-US countries ($P=0.062$). In this study, different regions of the United States were also compared. In April 2020, compared to 2019, the reduction in stress SPECT test was 77% in the Midwest, 87% in the northeast, 68% in the south, and 47% in the west ($P<0.001$). The decline was more pronounced in the northeast and the Midwest.

According to this study, cardiovascular imaging tests declined sharply during the pandemic; in that period (between April 2020 and March 2019 as the baseline), there were about three-quarters fewer stress SPECT procedures worldwide, nearly the same number as for the United States.

In their study, Hirschfeld et al. suggested that factors such as the spread of COVID, urban centers, outpatient imaging facilities, and staff redeployment resulted in fewer cardiac imaging services in the United States.

SPECT MPI findings

One of the seven papers published about SPECT MPI findings was a brief report journal article, two were conference abstracts, and the remaining three were journal articles of original research. Records are summarized in Table 6.

Using multivariable Cox analysis, Assante et al. found that abnormal MPI and a history of SARS-CoV-2 infection were predictive factors of CAD events in patients who had undergone SPECT MPI [49]. The annualized event rate among COVID patients with normal or abnormal MPI was not significantly different ($P=0.56$). However, abnormal MPI was associated with an increased event rate in patients without past SARS-CoV-2 infection ($P<0.001$). In both normal and abnormal TPD, patients with prior COVID infection had a higher event rate than those without previous infection. According to Assante and colleagues, subsequent SARS-CoV-2 infections are associated with increased cardiovascular events in the short term, independent of other cardiovascular factors. Furthermore, a history of COVID and an abnormal MPI were both associated with an increased risk of cardiovascular events among these patients. In conclusion, the COVID effect on the cardiovascular system may contribute to poor outcomes for patients with CAD.

In their study, published as a conference abstract, Aksu et al. examined 287 patients with stress SPECT MPI [50]. They classified patients into two groups: those with only GGOs on CT scans and those with both GGOs on CT scans and Methoxy Isobutyl Isonitrile Technetium-99 m (MIBI) involvement. There were GGOs observed in non-diagnostic CT scans of 11 of the 22 patients with a history of COVID-19, and ten patients had Tc-99 m-MIBI involvement along with GGOs. Patients with Tc-99 m-MIBI involvement had a median time between COVID diagnosis and MPI of 50.5 days. In contrast, patients with only GGOs on CT scans had a median time of 63.5 days, indicating no significant difference between the two ($P>0.05$).

The authors conclude that while imaging models correlated with clinical improvement in patients with a history of COVID-19 usually occur within the first two weeks following infection, they might persist for an extended period following diagnosis. This may also be accompanied by an increase in the uptake of radiopharmaceuticals.

The last five papers about SPECT MPI findings in the COVID-19 era all talk about MPI findings in patients who had MPI after the acute stage of COVID and in the post-COVID period.

Araz et al. categorized patients with SARS-CoV-2 infection within the past six months as their study group and patients who had not had COVID during that period as the control group [51]. The two groups were matched based on age and gender.

According to the analysis of the predominant reasons for MPI referral, dyspnea was more common among the study group patients than among the control group ($P<0.001$), but chest pain did not differ significantly between the two groups ($P=0.028$). A total of 85 patients (45.4%) had abnormal MPI results. Patients with a history of COVID were more likely to experience ischemia ($P<0.001$).

It was found that, regardless of MPI results, invasive evaluation with coronary angiography and treatment was more prevalent in the study group ($P=0.006$ and $P=0.015$). It was the same for the patients with abnormal MPI ($P=0.008$ and $P=0.015$, respectively). It was, however, not valid for the group with ischemic MPI results ($P=0.29$ and $P=0.06$, respectively).

According to Araz and colleagues, patients with COVID in the last six months are more likely to have ischemia in MPI, require CAG, undergo CABG, and begin medical therapy. According to Araz et al., MPI can be a reliable diagnostic tool for patients exhibiting cardiovascular symptoms in the late stages of COVID.

An additional study by Cap et al. examined 1888 patients, of whom 340 had a history of SARS-CoV-2 infection [52]. There were 340 of these patients, 26% ($N=88$) of whom had abnormal MPI results showing ischemia (N: 46, TPD > 10%), 64 of whom underwent CAG for coronary stenosis, and 11 had coronary stenosis greater than 50%. While out of 1548 patients without COVID history, 19% ($N=297$) had abnormal MPI results showing ischemia (N: 122, TPD > 10%), 192 underwent CAG angiography, and 53 had coronary artery stenosis of more than 50%.

Table 6 SPECT MPI findings

The first author	Country	Sample size and characteristics	Age (years)	Male gender %)	Study duration	Conclusion
Assante R	Italy	960 patients *(with known or suspected CAD)*	64 ± 10 *(Mean, SD)*	67%	January 2018–June 2019	During a short-term follow-up of patients undergoing stress MPI, subsequent COVID-19 infection was associated with a significantly higher cardiovascular event rate, independently of other cardiovascular risk factors COVID-19 and abnormal MPI both increased cardiac event risk in these patients CAD patients with COVID-19 infection may suffer a poor outcome due to its effects on the cardiovascular system
Araz M	Turkey	*of 179 patients:* 85 in study group *(confirmed prior COVID-19 infection)* 94 in control group *(non-COVID)*	*Study group:* 58.13 ± 9.07 *(Mean, SD)* *Control group:* 58.43 ± 9.42 *(Mean, SD)*	*Study group:* 50.5% *Control group:* 55.3%	*Study group:* August 2020-April 2021 *Control group:* January 2019-September 2019	The frequency of ischemia on MPI is much higher in patients with a history of COVID-19 Angiography, stent implantation, CABG, and medical therapy are also more common in these patients MPI can be used to investigate ischemia in patients presenting with cardiovascular symptoms late in COVID
Cap M	Turkey	*of 1888 patients:* 340 patients in COVID-19 group 1548 in non-COVID group	*COVID-19 group:* 55.8 ± 10.4 *(Mean, SD)* *Non-COVID group:* 56.1 ± 11.5 *(Mean, SD)*	*COVID-19 group:* 33% *Non-COVID group:* 35%	January 1st 2021-June 30th 2021	COVID-19 patients had higher ischemia rates in MPI than non-COVID-19 patients, and a prior COVID-19 infection could predict abnormal MPI CMD may cause symptoms like chest pain and shortness of breath in post-COVID-19 patients with ischemia in MPI and without critical coronary stenosis
Hasnie U	USA	15 patients with a history of COVID	60 (51–68) *(Median, Range)*	67%	March 2020-October 2020	The number of patients with MPI testing after COVID-19 infection will increase over time

Table 6 (continued)

The first author	Country	Sample size and characteristics	Age (years)	Male gender %)	Study duration	Conclusion
Bilge O	Turkey	*of 266 patients (with a history of COVID):* 157 in pneumonia group 109 in non-pneumonia group	57 (50–64) *(Median, IQR)*	30%	January 1st 2021-November 1st 2021	COVID-19 pneumonia could predict ischemia on SPECT-MPI Coronary ischemia may cause chest pain and shortness of breath in COVID-19 pneumonia patients
Koo B.S	USA	60 patients with a prior COVID infection			June 2020-March 2021	Even mild or asymptomatic COVID infections without hospitalization are associated with SPECT MPI defects These SPECT data match cardiac MRI findings previously reported
Aksu A	Turkey	287 patients with a prior COVID infection			October 2020-January 2021	The appearance of improvements in COVID patients' images may take more than two weeks During this interval, radiopharmaceutical uptake may also be observed

To assess the study's hypothesis, myocardial ischemia in non-obstructive coronaries, Cap and colleagues excluded 64 patients from both groups with coronary stenosis greater than 50%. In the remaining patients of the study, abnormal MPI results were found in 77 patients (23%) with a history of COVID and 242 patients (16%) without; after using Bayesian logistic regression, an essential connection between SARS-CoV-2 infection presence in history and abnormal MPI results was found. When a weakly informative prior was used, the posterior median odds ratio was 1.70 (95% CI, 1.20–2.40), and the estimated risk difference was 9.6% (95% CI, 1.8%–19.7%). Based on the findings of this study, there was a probability of more than 90% for the odds ratio to become more significant than 1. This indicated any level of abnormal MPI risk.

According to Cap and colleagues, patients with COVID had a higher ischemia rate than non-COVID patients, suggesting that previously confirmed infection with COVID may be an abnormal MPI predictor. Symptoms such as chest pain and shortness of breath, which can occur post-COVID in some patients, might be due to CMD in patients with ischemia in MPI and without critical coronary stenosis.

Hasnie et al. conducted an outpatient study where stress tests were used to evaluate chest pain or shortness of breath [53]. Most patients had normal perfusion, except for one patient (7%) who showed a scar on the left anterior descending artery distribution. The mean LVEF was 55%. Among 11 patients who underwent a pharmacologic stress test, one complained of chest pain after receiving Regadenoson, and more than half reported dyspnea, but other symptoms were not severe. 75% of the patients who underwent exercise tests reported non-limiting shortness of breath, and 25% reported mild chest pain.

In their published brief report Hasnie and colleagues concluded that more patients who recover from COVID require MPI to assess myocardial ischemia over time. Because of this, there is a growing need to do more research to come up with official protocols for nuclear imaging in this group.

Bilge et al. conducted a study in which patients who had previously been infected with COVID and had a thorax CT scan were included [54]. Based on the CT findings, 157 patients were divided into two groups: those with pneumonia (57%) and those without pneumonia (43%). They were admitted to a hospital's outpatient cardiology department with symptoms of chest pain, shortness of breath, or both. They underwent MPI testing after recovering from COVID. The median time between COVID and MPI was 154 days (IQR, 81–224).

It was found that 65 (24%) of these patients had ischemia findings on SPECT MPI. Coronary angiography was

performed for 54 of them, and 11 patients had at least 50% stenosis. There were no significant differences between pneumonia and non-pneumonia groups in terms of age, gender, diabetes, hypertension, hyperlipidemia, or smoking. The abnormal SSS score and rate of abnormal SPECT MPI score were higher in the pneumonia group due to ischemia ($P=0.002$ and $P=0.017$, respectively).

Bilge and his colleagues came to the conclusion that COVID-19 pneumonia could be an independent predictor of ischemia in SPECT MPI and that chest pain and shortness of breath in COVID patients might be related to coronary ischemia.

During the study of Koo et al. of 80 patients who recovered from COVID and were referred for stress imaging, 36 of whom had never been hospitalized for COVID and had no history of coronary artery disease, were subjected to stress SPECT MPI [55]. Perfusion defects were found in 77.8% of the patients. Among the patients with at least one perfusion defect, 71.4% had a septal perfusion defect, 67.8% had an inferior wall defect, and 35.7% had an anterior wall defect. Twenty of the twenty-one patients (95%) with an abnormal stress SPECT MPI and some angiographic evaluations afterward showed no signs of obstructive CAD.

As a result of the study, Koo and colleagues found a high prevalence of defects in stress SPECT MPI in patients with mild or asymptomatic COVID, which correlates with previous findings from cardiac MRI tests.

Other papers

The study by Scrima et al. also addresses SPECT MPI in the era of COVID-19 [56]. In this study, they designed an imaging protocol based on Regadenoson-stress 99 m-Tc-Tetrofsomin for single-day fast imaging. Patients were contacted by telephone four days before the test. They were asked about their COVID test positivity, their history of contact with an infected or suspected person, and their symptoms, such as coughing, fever, and breathing difficulties. The questionnaire was repeated on the day of the test.

For admission to the department, patients must have a fever below 37.5 and be symptom free of SARS-CoV-2 infection on the day of the test. The patients should have worn surgical masks and gloves. Social distance was observed during the test, and healthcare personnel wore personal protective equipment. Sixty-six patients who had imaging from April 7th to May 15th, 2020, did not exhibit COVID symptoms during telephone follow-ups. As of May 18th, all staff members had tested negative for COVID.

Using an extensive claims database (Pharmetric Plus), Skali et al. studied patients who had undergone pharmacological MPI between March 2020 and February 2021 [57]. A total of 6372 (3.5% of 179,803 patients) had a history of COVID-19 up to one year before the test. Skali and colleagues concluded that patients with a history of COVID a year before performing pharmacological stress MPI were more likely to incorporate a reversal agent without an increase in subsequent resource utilization or clinically significant costs. There may be no need to worry about pharmacological MPI in patients with a history of COVID-19.

Conclusion

In the aftermath of the COVID-19 pandemic, it is no longer a secret that the pandemic has changed the world as we knew it. The nuclear medicine imaging modality MPI SPECT has not been exempt from these changes.

We realized the value of CT scans accompanied by MPI SPECT and, by reviewing several case reports, the importance of interpreting those CTACs in the context of the possibility of patients having COVID. The CTACs should be interpreted upon discharge, particularly in regions with a high prevalence of COVID.

We also found that we should pay attention to the possible complications of COVID and long-COVID in patients with either a recent or distant history of SARS-CoV-2 infection. The importance of COVID history for patients with abnormal MPI was found to be significant since it may predict cardiovascular events.

A decrease in MPI procedures caused by the pandemic resulted in diagnostic delays, which will adversely affect patient outcomes in the coming years. This situation demands special attention and preparation from the nuclear medicine community. While SPECT MPIs have declined considerably worldwide, this decline has been even more pronounced in low- and middle-income countries. It appears that the pandemic has magnified the differences that have always existed in access to nuclear medicine imaging facilities. More research is needed in this area.

Appendix A search strings for all databases.

1. PubMed search string:

results

6th June, 2022

("post-acute COVID-19 syndrome" [Supplementary Concept] OR "COVID-19"[Mesh] OR covid[tiab] OR covid-19[tiab] OR covid-19[tiab] OR "long-covid*"[tiab] OR "long-haul covid*"[tiab] OR "post-acute covid*"[tiab] OR "persistent covid*"[tiab] OR "long covid*"[tiab] OR "long haul covid*"[tiab] OR "long hauler covid*"[tiab]*

OR "post acute covid"[tiab] OR "persistent covid*"[tiab] OR "chronic covid*"[tiab] OR "sars-cov-2"[tiab] OR "2019-ncov"[tiab] OR "corona virus"[tiab] OR "coronavirus"[tiab] OR "novel coronavirus"[tiab] OR "ncov-2019"[tiab] OR "severe acute respiratory syndrome coronavirus"[tiab] OR "postcovid*"[tiab] OR "post covid*"[tiab] OR "post-covid*"[tiab]) AND (("Myocardial Perfusion Imaging"[Mesh] OR "myocardial perfusion imaging"[tiab] OR "myocardial perfusion scan"[tiab] OR "myocardial scintigraphy"[tiab] OR "myocardial perfusion scintigraphy"[tiab] OR "myocardial mibg scintigraphy"[tiab] OR gmps[tiab] OR "myocardial ct perfusion"[tiab] OR "sestamibi myocardial scintigraphy"[tiab] OR "myocardial perfusion single-photon emission computed tomography"[tiab] OR "myocardial perfusion spect"[tiab] OR "spect myocardial perfusion"[tiab] OR "myocardial first-pass perfusion imaging"[tiab] OR "Cardiac-Gated Single-Photon Emission Computer-Assisted Tomography"[Mesh] OR "cardiac gated single photon emission computer assisted tomography"[tiab] OR "cardiac-gated spect"[tiab] OR "cardiac gated spect"[tiab]) OR (("Single Photon Emission Computed Tomography Computed Tomography"[Mesh] OR "single photon emission computed tomography"[tiab] OR spect[tiab] OR spects[tiab] OR "Perfusion Imaging"[Mesh]) AND ("Myocardium"[Mesh] OR myocard*[tiab])))*.

2. Scopus search string:

results

6th June, 2022

(TITLE-ABS-KEY("post-acute COVID-19 syndrome" OR "covid-19" OR covid OR covid19 OR "long-covid*" OR "long-haul covid*" OR "post-acute covid*" OR "persistent covid*" OR "long covid*" OR "long haul covid*"OR "long hauler covid*" OR "post acute covid*" OR "persistent covid*" OR "chronic covid*" OR "sars-cov-2" OR "2019-ncov" OR "corona virus" OR "coronavirus" OR "novel coronavirus" OR "ncov-2019" OR "severe acute respiratory syndrome coronavirus" OR "postcovid*" OR "post covid*" OR "post-covid*") AND (TITLE-ABS-KEY("myocardial perfusion imaging" OR "myocardial perfusion scan" OR "myocardial scintigraphy" OR "myocardial perfusion scintigraphy" OR "myocardial mibg scintigraphy" OR gmps OR "myocardial ct perfusion" OR "sestamibi myocardial scintigraphy" OR "myocardial perfusion single-photon emission computed tomography" OR "myocardial perfusion spect" OR "spect myocardial perfusion" OR "myocardial first-pass perfusion imaging" OR "Cardiac-Gated Single-Photon Emission Computer-Assisted Tomography" OR "cardiac gated single photon emission computer assisted tomography" OR "cardiac-gated spect" OR "cardiac gated spect") OR (TITLE-ABS-KEY("single photon emission computed tomography" OR spect OR spects OR "Perfusion Imaging") AND TITLE-ABS-KEY("Myocardium" OR myocard*))))*.

3. Embase search string:

results

6th June, 2022

("long COVID"/exp OR 'coronavirus disease 2019'/exp OR 'Severe acute respiratory syndrome coronavirus 2'/exp OR covid:ab,ti OR covid-19:ab,ti OR covid-19:ab,ti OR "long-covid*":ab,ti OR "long-haul covid*":ab,ti OR "post-acute covid*":ab,ti OR "persistent covid*":ab,ti OR "long covid*":ab,ti OR "long haul covid*":ab,ti OR "long hauler covid*":ab,ti OR "post acute covid*":ab,ti OR "persistent covid*":ab,ti OR "chronic covid*":ab,ti OR "sars-cov-2":ab,ti OR "2019-ncov":ab,ti OR "corona virus":ab,ti OR "coronavirus":ab,ti OR "novel coronavirus":ab,ti OR "ncov-2019":ab,ti OR "severe acute respiratory syndrome coronavirus":ab,ti OR "postcovid*":ab,ti OR "post covid*":ab,ti OR "post-covid*":ab,ti) AND (('myocardial perfusion imaging'/exp OR 'nuclear stress test'/exp OR "myocardial perfusion imaging":ab,ti OR "myocardial perfusion scan":ab,ti OR "myocardial scintigraphy":ab,ti OR "myocardial perfusion scintigraphy":ab,ti OR "myocardial mibg scintigraphy":ab,ti OR gmps:ab,ti OR "myocardial ct perfusion":ab,ti OR "sestamibi myocardial scintigraphy":ab,ti OR "myocardial perfusion single-photon emission computed tomography":ab,ti OR "myocardial perfusion spect":ab,ti OR "spect myocardial perfusion":ab,ti OR "myocardial first-pass perfusion imaging":ab,ti OR "cardiac gated single photon emission computer assisted tomography":ab,ti OR "cardiac-gated spect":ab,ti OR "cardiac gated spect":ab,ti) OR (('single photon emission computed tomography'/exp OR 'gated single photon emission computed tomography'/exp OR "single photon emission computed tomography":ab,ti OR spect:ab,ti OR spects:ab,ti OR 'scintigraphy'/exp) AND ('cardiac muscle'/exp OR myocard*:ab,ti)))*.

4. Web of Science search string:

results

6th June, 2022

(TS=("post-acute COVID-19 syndrome" OR "covid-19" OR covid OR covid19 OR "long-covid*" OR "long-haul covid*" OR "post-acute covid*" OR "persistent covid*"*

OR "long covid" OR "long haul covid*"OR "long hauler covid*" OR "post acute covid*" OR "persistent covid*" OR "chronic covid*" OR "sars-cov-2" OR "2019-ncov" OR "corona virus" OR "coronavirus" OR "novel coronavirus" OR "ncov-2019" OR "severe acute respiratory syndrome coronavirus" OR "postcovid*" OR "post covid*" OR "post-covid*") AND (TS=("myocardial perfusion imaging" OR "myocardial perfusion scan" OR "myocardial scintigraphy" OR "myocardial perfusion scintigraphy" OR "myocardial mibg scintigraphy" OR gmps OR "myocardial ct perfusion" OR "sestamibi myocardial scintigraphy" OR "myocardial perfusion single-photon emission computed tomography" OR "myocardial perfusion spect" OR "spect myocardial perfusion" OR "myocardial first-pass perfusion imaging" OR "Cardiac-Gated Single-Photon Emission Computer-Assisted Tomography" OR "cardiac gated single photon emission computer assisted tomography" OR "cardiac-gated spect" OR "cardiac gated spect") OR (TS=("single photon emission computed tomography" OR spect OR specs OR "Perfusion Imaging") AND TS=("Myocardium" OR myocard*))))).*

5. Cochrane Central Register of Controlled Trials via Ovid search string:

results

6th June, 2022

(("post-acute COVID-19 syndrome" OR "covid-19" OR covid OR covid19 OR "long-covid*" OR "long-haul covid*" OR "post-acute covid*" OR "persistent covid*" OR "long covid*" OR "long haul covid*"OR "long hauler covid*" OR "post acute covid*" OR "persistent covid*" OR "chronic covid*" OR "sars-cov-2" OR "2019-ncov" OR "corona virus" OR "coronavirus" OR "novel coronavirus" OR "ncov-2019" OR "severe acute respiratory syndrome coronavirus" OR "postcovid*" OR "post covid*" OR "post-covid*").ti,ab AND (("myocardial perfusion imaging" OR "myocardial perfusion scan" OR "myocardial scintigraphy" OR "myocardial perfusion scintigraphy" OR "myocardial mibg scintigraphy" OR gmps OR "myocardial ct perfusion" OR "sestamibi myocardial scintigraphy" OR "myocardial perfusion single-photon emission computed tomography" OR "myocardial perfusion spect" OR "spect myocardial perfusion" OR "myocardial first-pass perfusion imaging" OR "Cardiac-Gated Single-Photon Emission Computer-Assisted Tomography" OR "cardiac gated single photon emission computer assisted tomography" OR "cardiac-gated spect" OR "cardiac gated spect").ti,ab OR (("single photon emission computed tomography" OR spect OR specs OR "Perfusion Imaging").ti,ab AND ("Myocardium" OR myocard*).ti,ab))).*

Appendix B more sensitive pubmed search strings for two journals which had most papers among all sources.

A. Journal of Nuclear Cardiology search via PubMed:

results

6th June, 2022

"J Nucl Cardiol"[jour] AND (covid OR corona) AND (mpi OR myocardial perfusion OR scintigraphy OR spect OR single photon emission computed tomography).

B. European Journal of Nuclear Medicine and Molecular Imaging search via PubMed:

results

6th June, 2022

"Eur J Nucl Med Mol Imaging"[jour] AND (covid OR corona) AND (mpi OR myocardial perfusion OR scintigraphy OR spect OR single photon emission computed tomography).

Funding In order to prepare this paper, the authors declare that they have not received any governmental or non-governmental funding, grants, or other supports during the preparation of the manuscript.

Declarations

Conflicts of interest There is no conflict of interest reported by the authors.

Ethical approval This paper does not contain any studies with human or animal participants performed by any of the authors.

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