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Review Article

Cardiac imaging in cardiovascular complications due to COVID-19

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ABSTRACT

Cardiovascular complications are a common manifestation of acute phase and chronic phase of coronavirus disease 2019 (COVID-19) infection. Complications include cardiomyopathy, myocardial infarction, arrhythmias, heart failure, and deep venous thrombosis. Imaging is widely used in patients with suspected myocardial injury or myocarditis. Because of its availability and portability, transthoracic echocardiography (TTE) is used as the initial imaging modality in patients with suspected COVID-19 myocarditis. Echocardiographic studies performed on patients with suspected or confirmed COVID-19 should be as focused as necessary to obtain diagnostic views but should also be comprehensive enough to avoid the need to return for additional images. Following COVID-19 infection, a variety of persistent respiratory, neurological, cardiovascular, and other symptoms can persist for weeks, months, or even years. A cardiac examination and any resulting abnormalities in the structure and function of the heart may occasionally last for several months following a COVID-19 diagnosis. This is referred to as long COVID syndrome. Cardiac magnetic resonance (CMR) imaging has often been used clinically to complement echocardiography, particularly tissue characterization imaging which demonstrated subclinical myocardial edema with or without fibrosis in patients recovered from illness.

1. Introduction

Cardiovascular complications associated with SARS-cov-2 infection are common and lead to high mortality in acute and post-acute infection. Acute myocardial infarction, myocarditis, pericarditis, vasculitis, takotsubo cardiomyopathy, arrhythmia, thromboembolism, pulmonary hypertension, and heart failure, which can include both left and right heart failure, are among the cardiac conditions brought on by COVID-19.[1,2] Long COVID syndrome is defined by WHO 2022 as a syndrome that continues or development of new symptoms 3 months after the initial SARS-cov-2 infection, with these symptoms lasting for at least 2 months with no other explanation. Estimated of the long COVID incidence among individuals with COVID-19 who are not hospitalized range from 7.5% to 41%, according to the CDC 2022.

The role of other cardiac imaging modalities has evolved during the pandemic. Cardiovascular imaging, primarily echocardiography, has played a significant role when the history, physical examination, and other supporting examinations have failed to establish a diagnosis. Several imaging modalities are available to provide information to establish the diagnosis and management of COVID-19-related cardiovascular disease. Depending on the clinical conditions of each patient's disease, not all these modalities must be done for one patient at the same time. [3–6]

2. Echocardiography

One of the main methods for evaluating the heart in individuals with potential or confirmed COVID-19 is echocardiography. Because this examination is portable, it can be utilized on patients who cannot be transported, such as those in the emergency room or intensive care unit. In acute settings, Point-of-care Ultrasound (POCUS) can give rapid assessment of the cardiac structure and function especially in non-transportable patients or patiens in intensive units. In chornic or stable patient settings, Transthoracic Echocardiography (TTE) can give more thorough examination and detailed information of the cardiac and structural function, both are frequently used in the COVID-19 era. Due to the significant risk of transmission, transesophageal echocardiography (TEE) testing is not suggested for routine use in acute phase cases of COVID-19.[7,8]

POCUS (Point-of-care Ultrasound)

Point-of-care Ultrasound offers a rapid assistance for assessing patients presenting with acute dyspnea determining the need for additional imaging examinations (TTE, computed tomography, etc.). The American Society of Echocardiography (ASE) has modified POCUS to aid diagnostics in both suspected and confirmed COVID-19 cases. POCUS can be performed serially in cases of long COVID syndrome to identify any changes in the examination results. The heart, lungs, and blood vessels are all evaluated during a POCUS assessment. [3–5,10]

The POCUS component's lung ultrasound examination, among other things, assesses the progression of COVID-19 disease. Thickening and irregularity of the pleura and B-lines are typical lung findings in COVID-19 pneumonia. More confluent B lines are found in more severe cases. POCUS can be used to evaluate other lung pathologies in critical situations such as pneumothorax and massive pleural effusion. Guidelines now include vascular POCUS examination in acute conditions. In critical conditions, examination of the inferior vena cava and jugular vein

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Table 1. Cardiac POCUS indications[8,11]

Early identification of worsening heart function
For diagnostics and monitoring. POCUS can be used to assess changes in heart function at any time with rapid assessment amidst limited use of Personal Protective Equipment (PPE) and the situation of COVID-19 patients
Identify cardiovascular disorders that are potentially related to COVID-19, including: - Presence of pericardial effusion and/or myocarditis which may progress to shock - The presence of a hypercoagulable state which can develop into deep vein thrombosis or acute pulmonary embolism, early identification can reveal disturbances in the structure and function of the right ventricle and acute pulmonary hypertension - Global or regional impairment of left ventricular systolic function associated with myocarditis, stress-induced cardiomyopathy, and coronary microvascular thrombosis

Source: Goerlich E, Minhas AS, Mukherjee M, et al. Multimodality Imaging for Cardiac Evaluation in Patients with COVID-19.

pulsations is critical for assessing hemodynamics. POCUS examination can detect deep vein thrombosis in COVID-19 patients who have been lying down for an extended period.[5,6,11,12,14,15]

POCUS is not routinely performed on COVID-19 patients, whether they are suspected or confirmed. In patients with suspected heart or blood vessel complications, this examination is used as the first line of defense. POCUS examinations include heart chambers, heart valves, myocardial assessment, lung assessment, and blood vessel examinations. The main benefit of using POCUS as a first line treatment in patients with COVID-19 is that it reduces exposure to medical personnel and other examination rooms, allowing for more efficient use of Personal Protective Equipment (PPE). Low imaging resolution, subjective nature (depending on operator experience), and inability to immediately convert a POCUS study into a full examination are all disadvantages of POCUS. There are cases where POCUS can answer clinical questions and support the diagnosis.[2,8,11]

Transthoracic echocardiography (TTE)

When evaluating the heart in COVID-19, TTE is the most often utilized imaging modality. In the midst of the COVID-19 pandemic, the American Society of Echocardiography has issued guidelines to help physicians and healthcare professionals use TTE in a safe, efficient, and appropriate manner. The risk of virus transmission is one of TTE's weaknesses, and the main reason it is not recommended for routine use in COVID-19 patients who do not have clinical indications of heart problems.[3] TTE ultrasound images can provide valuable information about the structure and function of the heart. Based on an international prospective analysis of 1,216 COVID-19 patients receiving TTE, the most common reasons for the test were increased cardiac biomarkers (26%) and right heart failure (20%), followed by suspected heart failure (40%). The left and right ventricles' functional assessment is crucial in patients who may have cardiomyopathy, myocarditis, myocardial infarction, pulmonary hypertension, or pulmonary embolism. TTE can help monitor the patient's hemodynamics in the intensive care unit, identifying patients at high risk of ventilator failure and cardiac involvement, and determining the need for other hemodynamic aids such as Extracorporeal Membrane Oxygenation (ECMO).[13,16]

Echocardiography should be conducted only in patients with probable or proven COVID-19 if the results will alter the patient's medication. Heart failure/myocarditis, substantial or life-threatening arrhythmias, cardiac tamponade, and cardiogenic shock or hemodynamic instability are all indications for TTE in patients with confirmed COVID-19. If there is no evidence of urgency, the TTE examination can be postponed until the infection condition has been treated.[17,18] In patients of extended COVID syndrome, echocardiography is used to look for abnormalities in heart anatomy and function. Several investigations have shown heart abnormalities on echocardiography in asymptomatic patients following COVID-19.[19,20]

3. Computed Tomography (CT)

CT is an excellent test for early diagnosis of COVID-19 pneumonia. This modality is simple to use, quick, readily available, and sensitive, however it is not widely distributed. It also provides great spatial resolution, fast speed, and tissue characterization. CT of the chest without contrast mainly ordered to evaluate the pathology of the lungs, findings include multifocal ground glass opacities (GGO) and patchy consolidation.[3,8]

In the COVID-19 era, literature has primarily discussed the utility of CT in evaluating patients for pulmonary embolism, myocarditis, acute coronary syndrome, and the exclusion of left atrial thrombi before cardioversion. Nevertheless, there is also value in evaluating patients for other CV problems. The anatomy of the heart chambers and major arteries, as well as the existence of pericardial effusion, are the main areas of CT insight into cardiac structure and function when used as a non-contrast, non-cardiac-gated scan. [2,3,7]

Coronary CT angiography can reduce the need for invasive coronary catheterization and the danger of exposure for catheterization laboratory personnel. Patients who have a suspected acute myocardial infarction but no clinical evidence are eligible for a coronary CT scan before catheterization. Because CT can detect early-onset pneumonia in asymptomatic patients, routine chest scans are not recommended in cases where CT is indicated. In selected cases, the Society for Cardiovascular CT advises delaying CT exams in patients with probable or confirmed COVID-19. Urgent Coronary Computed Tomography Angiography (CCTA) is indicated in circumstances involving high-risk patients diagnosed with coronary artery disease, thrombus in the left atrial and ventricular appendices, pulmonary embolism, aortic dissection, prosthetic valve thrombosis, endocarditis, or individuals in need of immediate attention.[5,6,21]

Urgent CCTA is indicated in cases of high-risk patients diagnosed with coronary artery disease, thrombus in the left atrial and ventricular appendices, pulmonary embolism, aortic dissection, prosthetic valve thrombosis, endocarditis, or individuals in need of immediate medical care. Although most CT scanners available today are able to capture the coronary arteries in high resolution, clinical and supportive tests such as cardiac enzymes and d-dimer values are still required. Furthermore, CT angiography can rule out a left atrial appendix thrombus, which can be utilized to consider cardioversion in patients with atrial fibrillation and restrict operator exposure to transoesophageal echocardiography exams.[2,3,5,22]

Although elevation of D-dimer is able to rule out deep vein thrombosis and PE in outpatients with a low or intermediate clinical probability of PE, D-dimer levels increase for around 7 days during the PE event, and late evaluation may lead to underestimated determination. Therefore, CT scans also have an important role in diagnosing pulmonary embolism in COVID-19 patients. Pulmonary embolism in COVID-19 patients seems to be predominantly distributed in segmental arteries of the right lung, an assumption that needs to be approached in future research.[23,24]

4. Cardiac Magnetic Resonance (CMR)

With its Short Tau Inversion Recovery (STIR) sequence and mapping approaches (T2 and Native-T1), CMR is the preferred imaging modality for diagnosing acute myocarditis. It may detect focal or diffuse myocardial edema with high sensitivity. In addition to detecting myocarditis, CMR can identify the existence of an arrhythmogenic substrate in cases of arrhythmia. Although myocardial biopsy is the gold standard for diagnosing myocarditis, one of the key advantages of CMR is its ability to assist in discriminating between ischemia and nonischemic myocardial injury. Necrotic regions identified by late gadolinium enhancement (LGE), extensive extracellular volume fraction (ECV) expansion, and hyperemia may be associated with CMR. The distribution of myocardial LGE was calculated as the number of segments in all patients in accordance with the American Heart Association 17-segment model and was used to define the extent of involvement.

Table 2. Recommended imaging examination scenarios for patients with certain clinical conditions[8,25]

Imaging Modalities	Advantage	Disadvantage	Findings in COVID-19 Cases
Echocardiography	Quick No radiation Can be done *bedside* Cost Effective	Imaging quality is operator dependent, affected by the patient's ventilation.	Dilatation and dysfunction of right ventricular Left ventricular systolic and diastolic dysfunction. Wall motion abnormalities Stress cardiomyopathy Pulmonary Hypertension Right & left ventricular tension decreases. Pericardial effusion Filling pressure increases
POCUS (*Point-Of-Care Ultrasound)*	Quick Can be done *bedside* No radiation Cost Effective Simple Equipment	Operator dependent Functionally limited compared to echocardiography	Functional and structural of right and left ventricular abnormalities. Pericardial effusion Pleural effusion B lines (indicates interstitial edema on lung ultrasound)
CCT/CTPA/CTA	Quick High Resolution Cost-Effective	Radiation Using contrast agent	Pulmonary embolism Cardiac chamber dilatation Pericardial Effusion
CMR	High Resolution No Radiation	Patient's Incompatibility	Ischaemic and non ischaemic injury *Stress cardiomyopathy* Myocarditis Pericarditis Cardiac chamber dilatation Abnormal strain
Nuclear Imaging	Localize inflamation	Low Resolution Longer duration Radiation	Valvular inflammation in endocarditis Myocardial inflammation in myocarditis

CCT = Cardiac computed tomography; CMR = cardiac magnetic resonance imaging; CTA = computed tomographic angiography

Currently, several case studies document CMR findings in SARS-cov-2 patients that are consistent with acute myocarditis. Myocardial edema can be important for CMR identification in some situations, highlighting the need for mapping techniques in CMR procedures in COVID-19 patients with suspected myocarditis. In addition, symptoms of inflammation and fibrosis may occur. Microfibrosis is caused by an increase in T1 relaxation periods, whereas microinflammation is caused by an increase in T2 relaxation times. As a result, in cases of COVID-19 in patients who do not require ICU care but have a clinical presentation and laboratory indicators that imply acute cardiac inflammation, CMR may be used to confirm the diagnosis of acute myocarditis. This can be done after ruling out other possible diagnoses, such as ACS and HF, using easily available imaging, such as a cardiac CT scan or TTE.[2,5,7,8,22,25]

In most cases, asymptomatic patients with suspected or confirmed COVID-19 cases are not recommended to have CMR studies. The greatest study to date to investigate the value of CMR in COVID-19 patients was conducted through a systematic examination of 34 trials, involving 199 individuals in the sample. This study found that T2/short-T1 inversion recovery (STIR) edema, LGE, and myocarditis (40%) with severe T1 and T2 mapping anomalies were the most prevalent diagnoses seen by CMR in this cohort. MINOCA, stress cardiomyopathy, and pericarditis are a few more important conditions that CMR can identify.[3,5,8]

5. Nuclear Imaging

Fluorodeoxyglucose (FDG) positron-emission tomography (PET) was used in place of TEE during the COVID-19 pandemic to assess possible myocarditis. Elective nuclear cardiology studies, like other modalities, can be postponed in accordance with the health protocols at each health facility. To restrict aerosol transfer, a cardiac examination with a pharmacological exercise load is more advised than an exercise stress test under current settings. In general, because to the limitations inherent in nuclear imaging studies, this modality has shown minimal clinical usefulness in the evaluation of COVID-19 patients. FDGPET imaging is being employed in the clinical diagnosis and risk assessment of various myocarditis, particularly cardiac sarcoidosis. This utility enhances the examination of COVID-19 myocarditis.[3,8]

Comparison of multimodality imaging in clinical practice

Each center that handles COVID-19 patients, employs a different set of imaging modalities. The aim is to minimize the operator's risk of exposure and to employ imaging only when clinical suspicion exists and in patients who truly require it. The following is a flow chart of imaging modalities that can be employed depending on the status of each patient.[12,26]Each imaging modality has advantages and weaknesses in its application. As a result, the choice of imaging modality to be employed is based on clinical needs and is tailored to the resources of each hospital. The table below shows a comparison of imaging modalities:[2,8,25]

Imaging safety performance in the COVID-19 era

In general, imaging as a diagnostic support is needed in COVID-19 patients, where this diagnostic will be related to the therapy given. An echocardiography is one type of imaging that is commonly employed in the COVID-19 era. Given the high number of infected healthcare professionals, the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI) urge that all elective echocardiograms be postponed, particularly in probable and confirmed COVID-19 cases. However, the clinical presentation of acute heart disease and the underlying cardiovascular disease must be detected as soon as possible, as it can typically cause greater mortality than COVID-19 infection. In general, the Italian Society of Echocardiography and Cardiovascular Imaging (SIECVI) advises cardiologists to distinguish between urgent and non-urgent TTE indications based on their individual assessment.[2,4,5,9]

Infection control can be accomplished by protecting medical personnel and maintaining equipment. Equipment maintenance is crucial to preventing transmission. Some institutions do not use ECG stickers; instead, they cover probes and devices with single-use plastic. It's important to keep in mind that the benefits of using a protective cover must be weighed against the risks of poor-quality images and longer scanning times. Some institutions only allow the use of specific tools or probes on patients who have an infection, whether it is suspected or proven. Even though most household disinfectants are effective against SARS-cov-2, care should be used when cleaning

equipment. Echocardiography equipment and probes should be thoroughly cleaned, ideally in the patient's room and then again in the hallway. Cleaning requirements differ. Though they are easier to clean than laptops, portable computers must be used carefully considering the possible loss of functionality and image quality. Each machine's cleaning process can be reviewed with the equipment provider, where disinfection guidelines are provided based on each vendor, as cleaning methods vary and can affect how well a machine operates. As advised by the seller, the TEE probe should be thoroughly cleaned indoors, taking care of the cord and handle as well. It should then be moved to a sealed container for immediate disinfection. Limiting the number of echocardiography professionals who scan patients is another way to prevent in addition to maintaining equipment. It is important to give careful thought to employees who might be especially vulnerable to severe COVID-19 issues. Medical professionals who are immunocompromised, over 60, have concurrent or chronic illnesses, or are pregnant may be able to avoid coming into contact with COVID-19 patients. The primary goal of imaging that is directly related to medicine is to take the necessary images to answer clinical issues in patients who have probable or proven COVID-19 in order to minimize the amount of time that patients spend in touch with medical personnel and equipment.[2,5,12,14,16]

To prevent the virus from spreading, imaging must be performed in accordance with the requirements of each location. It is critical to wash your hands thoroughly and frequently. The level of PPE necessary in some institutions may be determined by the level of patient risk associated with COVID-19 (low risk, moderate risk, or high risk). PPE can be classified into numerous levels or categories.[13,14,16]

- Standard care involves hand washing or hand sanitation and use of gloves and a surgical mask
- Droplet prevention measures include gowns, gloves, head coverings, face masks and eye protection.
- Airborne precautions add special masks (e.g. N-95 or N-99 respirator masks, or powered air-purifying respirators – PAPR systems), and shoe covers.

The level or type of TTE and echocardiographic stress risk may influence the local use of each PPE component. Due to the increased danger of aerosolization, airborne precautions are essential during TEE for both probable and confirmed cases. Patients who are symptomatic and undergoing routine echocardiography examinations may also be given surgical masks. It is vital to emphasize that the type of PPE utilized in each circumstance will be determined by local institutional policies and resources.[14,15,21,27]

6. Conclusion

Imaging studies are critical in establishing a diagnosis and controlling cardiovascular therapy in patients with suspected or confirmed COVID-19 instances. Not all imaging modalities are used on the same patient at the same time. Elective and non-urgent examinations should be postponed until the infection status improves. Urgent examination should only be performed if it will alter the medication or management given. Medical professionals must also minimize their exposure to patients when performing imaging examinations, and complete PPE must be utilized in accordance with each institution's regulations to prevent transmission.

7. Declaration

7.1 Ethics Approval and Consent to participate
Not applicable.

7.2. Consent for publication
Not applicable.

7.3 Availibility of data and materials
Data used in our study were presented in the main text.

7.4 Competing interests
Not applicable.

7.5 Funding Source
Not applicable.

7.6 Authors contributions
Idea/concept: LUK. Design: LUK. Control/supervision: DS, AF, BS, SDH. Data collection/processing: LUK. Analysis/interpretation: LUK, DS. Literature review: LUK. Writing the article: LUK. Critical review: DS, AF, BS, SDH. All authors have critically reviewed and approved the final draft and are possible for the content and similarity index of the manuscript.

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