Original Article

Subclinical Left Ventricular Systolic Dysfunction Detected by 2D Speckle-Tracking in Young Adults Post–COVID-19 Recovery

Mohamed Naseem[1*], MD; Amr Alkassas[1], MD; Sameh Samir[1], MD

ABSTRACT

Background: Coronavirus disease 2019 (COVID-19) was declared as a pandemic by the World Health Organization (WHO) on March 11, 2020. Apart from respiratory findings, cardiac involvement has been highlighted by some studies. COVID-19 is increasing rapidly among young adults. The present study was designed to evaluate left ventricular function using speckle-tracking echocardiography in young adult COVID-19 patients who underwent home recovery.

Methods: The study assessed 40 patients aged between 18 and 39 years who recovered at home from COVID-19 and 20 healthy control subjects. All the participants underwent evaluations of left and right ventricular function via the conventional and global longitudinal strain (GLS) technique measured by speckle-tracking echocardiography.

Results: Heart rate was significantly higher in the post–COVID-19 group (*P*=0.024). The patients were assessed for a mean period of 38.8 days (standard deviation=10.9 d) after negative COVID-19 testing. In the post–COVID-19 group, 19 patients (47%) reported ongoing dyspnea: 13 had dyspnea during ordinary daily activities and 6 had dyspnea during less-than-ordinary daily activities. Nine patients (23%) had chest pain, 8 (20%) had palpitations, 22 (55%) had fatigue, and 4 (10%) had joint pain. The left ventricular GLS value for the post–COVID-19 group was significantly impaired compared with the control group (*P*=0.006).

Conclusions: Among our young adult patients, who had recovered from COVID-19 at home, left ventricular GLS was affected, which may indicate the subclinical impairment of left ventricular systolic function. ***(Iranian Heart Journal 2022; 23(2): 106-115)***

KEYWORDS: LV ventricular function, COVID-19, Speckle-tracking echocardiography

[1] Cardiovascular Medicine Department, Tanta Faculty of Medicine, Egypt.

***Corresponding Author**: Mohamed Naseem, MD; Cardiovascular Medicine Department, Tanta Faculty of Medicine, Egypt.
Email: mohamednasim2011@gmail.com **Tel:** +201224332615

Received: October 25, 2021 **Accepted:** December 11, 2021

Coronavirus disease 2019 (COVID-19) has been considered a global outbreak since March 2020. Following its initial outbreak, researchers were focused solely on the effects of the disease on the respiratory tract. Nonetheless, data have emerged since showing that COVID-19 could have adverse cardiac effects, especially in patients with pre-existing cardiovascular comorbidities.[1]

Among hospitalized patients with COVID-19, high-sensitivity cardiac troponin, a

marker of myocardial damage, is elevated in 12% to 15% of patients and up to 30% in more severe cases, with this elevation being associated with increased adverse outcomes.[2,3] Multiple pathophysiological mechanisms have been proposed for cardiac involvement. They include the direct effect of the SARS-CoV-2 virus on myocytes through angiotensin-converting enzyme II receptors; plaque rupture due to inflammation; high cardiac output, causing increased cardiac stress; and increased coagulability, causing stent thrombosis.[4] However, there is a dearth of data on non-hospitalized patients, representing the majority of cases in Egypt, not least in the young adult group (18–39 y). In other words, it has yet to be determined whether this group of patients suffers from cardiac involvement. Although it was initially thought that senior citizens were affected the most by COVID-19, recent data have shown that hospitalized young adults with COVID-19 have a double death rate in comparison with patients in the same age group with acute myocardial infarction.[5]

Persistent symptoms after the acute phase of the disease are detected in between 10% and 20% of patients.[6] Long-standing symptoms include dyspnea, palpitation, chest pain, fatigue, and myalgia.[7] The mechanism of these symptoms is not known yet, but inflammatory reaction and vasculitis may be responsible.[8] Accurate evaluation of myocardial function allows the detection of patients with myocardial affection. The calculation of the ejection fraction (EF) using the biplane method is the most widely used method of measuring systolic function, yet this method may not represent the actual myocardial function in certain conditions where subtle myocardial dysfunction is present. Two-dimensional (2D) speckle-tracking echocardiography (STE) detects impaired systolic function even in the presence of a normal EF.[9]

The present study aimed to evaluate left ventricular (LV) function using 2D-STE in young adult patients who presented with post-acute illness symptoms following COVID-19 recovery at home.

METHODS

Study Population

The present study prospectively enrolled 40 patients aged between 18 and 39 years who were diagnosed with COVID-19 by reverse transcription-polymerase chain reaction assays between August and December 2020. Patients were identified from those in the post–COVID-19 assessment clinic and cardiology outpatient clinic. Additionally, 20 healthy subjects matching the patients for age were included as the control group.

Informed written consent was taken from all the patients, and the study protocol was approved by the local ethics committee.

During the enrollment period, 50 consecutive patients (26 patients referred for cardiac evaluation from the post–COVID-19 assessment clinic and the other 24 patients were self-presenting at the cardiology outpatient clinic) were screened for admission to the study.

Patients who underwent home recovery were recruited in the study if they had a normal LV systolic function by 2D echocardiography and negative results on a swab test after the isolation period.

The exclusion criteria were composed of coronary artery disease (evidenced by medical history, electrocardiography, and regional wall motion abnormalities by echocardiography), moderate or severe valvular lesions or congenital heart disease, systemic hypertension, diabetes mellitus, pulmonary hypertension, arrhythmias, severe renal and liver diseases, poor image quality, and requiring hospitalization during COVID-19 illness.

For various reasons, 10 patients were not considered eligible: 4 patients had poor

echocardiographic views, 1 patient had atrial fibrillation, 2 patients had valvular heart disease, and 3 patients refused to participate in the research.
Laboratory tests, including serum creatinine, C-reactive protein, and serum troponin, were done.

Echocardiography
Two-dimensional and Doppler echocardiographic studies were performed on all the participants with a commercially available machine (M5S probe, GE Vivid E9 echocardiographic system) equipped with a 2.5 MHz transducer.

LV systolic function
M-mode echocardiography was utilized to measure the LV septum and the LV posterior wall end-diastolic thickness. LVEF, left ventricular end-systolic volume (LVESV), and left ventricular end-diastolic volume (LVEDV) were measured by the biplane method of discs.[10]
Transmitral pulsed-wave Doppler was recorded, and the peaks of early diastolic filling (E) and late diastolic filling (A) were measured.
Tissue Doppler imaging was done on the mitral annulus in the apical 4-chamber view by placing the sample volume over the septal mitral valve annulus. The values of s' and è were measured, and E/ è was obtained. Isovolumic relaxation time was also measured as the time between the end of wave S' to the beginning of wave è.[11]

Right ventricular (RV) function
Tricuspid annular plane systolic excursion (TAPSE) was measured in 2D M-mode echocardiograms from the 4-chamber view, positioning the cursor on the lateral tricuspid annulus and measuring the amount of the longitudinal displacement of the annulus at peak systole.[12]
Pulmonary artery systolic pressure (PSAP) was calculated as the difference in pressure between the RV and the right atrium using the peak velocity (Vmax) of the tricuspid regurgitation in the continuous-wave Doppler trace. The simplified Bernoulli equation (PSAP = 4(Vmax)2 + right atrial pressure) was used.[13]

2D-SET
The analysis of LV global longitudinal strain (GLS) was performed with high-quality ECG-gated images from the apical 4-, 3-, and 2-chamber views using conventional 2D grayscale imaging. The images were obtained in a breath-hold to avoid any breathing artifacts. Three consecutive cardiac cycles were recorded and averaged at a rate of at least 50 frames per second (Fig. 1). Manual tracing of the endocardial borders in the end-systolic frame was performed, and the width and shape of the region of interest were adjusted manually.[14]

Chest Computed Tomography (CT) Findings During Acute Illness
A semiquantitative CT severity scoring was calculated to evaluate lung involvement. Each of the 5 lung lobes was scored on a scale of 0 to 5 according to the extent of the anatomic affection, with 0 indicating no involvement; 1, less than 5% involvement; 2, 5% to 25% involvement; 3, 26% to 49% involvement; 4, 50% to 75% involvement; and 5, more than 75% involvement.
The resulting total CT score was the sum of the individual lobar scores and ranged from 0 to 25.[15]

Reproducibility
All the measurements were performed by an experienced echocardiographer. Intra- and interobserver variabilities were evaluated using the coefficient of variation in 15 randomly selected cases. Data were stored in cine loop format and analyzed offline.

Intraobserver variability was assessed by having the same investigator perform remeasurement on 2 separate occasions. For the evaluation of interobserver variability, re-analysis was done by a second investigator, who was blinded to the first observer's measurements.

Statistical Analysis

The data were analyzed statistically using SPSS, version 20.0 (Armonk, NY: IBM Corp). The Kolmogorov–Smirnov was applied to examine whether variables were normally distributed. The χ^2 test (Monte Carlo) was utilized to compare qualitative variables. Additionally, the Student *t* test was employed to compare 2 groups of normally distributed quantitative variables, while the Mann–Whitney test was used to compare 2 groups of non-normally distributed quantitative variables. A *P* value of less than 0.05 was considered statistically significant. Further, the G Power tool (Franz Faul, University of Kiel, Germany, version 3.1.9.4) was used to calculate the power of the sample size with a 0.05 α and a 0.8 effect size. The calculated power value was 0.89 according to post hoc-type power analysis.

RESULTS

The study recruited 40 young adults after home recovery from COVID-19 (the case group) and 20 healthy subjects (the control group). The baseline clinical characteristics of the 2 study groups are presented in Table 1.

No significant differences were detected between the 2 groups regarding age, sex, dyslipidemia, smoking status, history of chronic obstructive pulmonary disease or asthma, systolic blood pressure, diastolic blood pressure, and body mass index. Heart rate was significantly higher in the post–COVID-19 group (*P*=0.024).

The patients were evaluated for a mean period of 38.8 days (standard deviation [SD]=10.9 d) after negative COVID-19 testing. Meanwhile, the duration since confirmed COVID-19 was 67.5 days (SD=12.3 d).

In the post–COVID-19 group, 19 patients (47%) reported ongoing dyspnea: 13 had dyspnea during ordinary daily activities and 6 patients had dyspnea during less-than-ordinary daily activities. Nine patients (23%) had chest pain, 8 (20%) had palpitations, 22 (55%) had fatigue, and 4 (10%) had joint pain.

Regarding medications received during COVID-19 illness, 8 patients (20%) received hydroxychloroquine, 35 (88%) received antibiotics, 10 (25%) received anticoagulation, and 7 (18%) received steroid therapy.

Concerning laboratory blood tests, there were no significant differences between the 2 groups vis-à-vis serum creatinine, troponin, and C-reactive protein levels. Blood oxygen saturation at the study time was 96.8% (SD=1.4). The CT chest severity score was 8.7 (SD=4.7).

The echocardiographic characteristics of the study population are depicted in Table 2.

Table 1: Clinical characteristics of the studied groups

Variables	Post–COVID-19 (n = 40)	Control (n = 20)	*P* value
Age, y	32.9 ± 4.2	32.8 ± 4.3	0.931
Male %	21 (52.5%)	11 (55%)	0.855
Dyslipidemia	6(15%)	4(20%)	1.000
Current smoker	6 (15%)	4 (20%)	1.000
COPD or asthma	2(5%)	1(5%)	1.000
Systolic blood pressure (mm Hg)	128.4 ± 11.3	124 ± 8	0.127

Diastolic blood pressure (mm Hg)	88.3 ± 5.5	86 ± 5.2	0.134
Heart rate (bpm)	78.6 ± 8	73.3 ± 9.1	0.024
BMI	26.8 ± 3	27.1 ± 2.4	0.701
Duration since negative swab, d	38.8 ± 10.9	–	–
Duration since confirmed COVID-19, d	67.5 ± 12.3	–	
Symptoms			
Dyspnea	19 (47%)	–	–
Chest pain	9 (23%)	–	
Palpitations	8 (20%)	–	
General exhaustion-fatigue	22 (55%)	–	
Joint pain	4 (10%)	–	
Medications Received			
Hydroxychloroquine	8 (20%)	–	-
Antibiotic	35 (88%)	–	
Anticoagulation	10 (25%)	–	
Steroid	7 (18%)	–	
Laboratory Test Results			
Troponin (ng/mL)	0.4 ± 0.2	0.4 ± 0.2	0.820
Serum creatinine (mg/dL)	1.1 ± 0.2	1.2 ± 0.2	0.699
CRP (mg/dL)	0.6 ± 0.4	0.5 ± 0.3	0.843
SO_2 at the time of the study	96.8 ± 1.4	-	-
CT chest score during acute illness	8.7 ± 4.7	–	-

Values are expressed as mean ± SD or n (%).
COVID-19, Coronavirus disease 2019; COPD, Chronic obstructive pulmonary disease; BMI, Body mass index; CRP, C=reactive protein; SO_2, Blood oxygen saturation; CT, Computed tomography

Table 2: Echocardiographic characteristics of the studied groups

Variables	Post–COVID-19 (n = 40)	Control (n = 20)	*P* value
LV septum thickness at end-diastole, mm	0.9 ± 0.1	0.9 ± 0.1	1.000
LVPW thickness at end-diastole, mm	1.1 ± 0.1	0.9 ± 0.1	0.906
LVEDV, mL/m^2	126.3 ± 20.5	116.7 ± 15.4	0.069
LVESV, mL/m^2	47.9 ± 12.2	43 ± 10.9	0.131
EF, %	61.8 ± 5.9	64.6 ± 6.1	0.088
Mitral peak E, m/s	0.8 ± 0.1	0.8 ± 0.1	0.444
Mitral peak A, m/s	0.7 ± 0.1	0.7 ± 0.1	0.616
LV IVRT, ms	97 ± 16.2	90 ± 14.9	0.111
Mitral E/ è	10.9 ± 1.5	11.3 ± 1.7	0.423
Peak S′, cm/s	11.5 ± 1.5	11.2 ± 1.2	0.398
LV GLS, %	-18.6 ± 1.9	-20.0 ± 1.5	0.006
PASP, mm Hg	31.6 ± 4	31.1 ± 4.3	0.625
TAPSE	18.4 ± 1.9	19.2 ± 2.7	0.196
Pericardial effusion	3(7%)	-	-

Values are expressed as mean ± SD or n (%).
COVID-19, Coronavirus disease 2019; LVEDV, Left ventricular end-diastolic volume index; LVPW, Left ventricular posterior wall; LVESV, Left ventricular end-systolic volume; EF, Ejection fraction; E, Peak flow velocity during the early rapid filling phase; A, Peak flow velocity during atrial contraction; IVRT, Isovolumic relaxation time; E/ è, The ratio of the early flow velocity to the early annular velocity; S′, Systolic annulus velocity; LV, Left ventricular; GLS, Global longitudinal strain; PASP, Pulmonary artery systolic pressure; TAPSE, Tricuspid annular plane systolic excursion

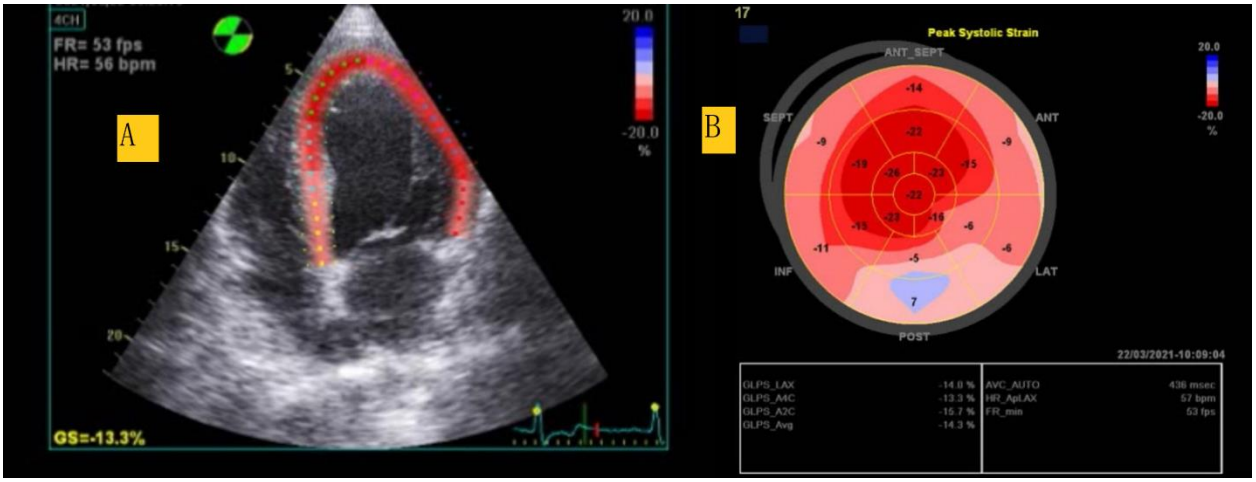

Figure 1: The images depict A) left ventricular global longitudinal strain (apical 4-chamber analysis) and B) bull's eye, showing a reduced overall left ventricular global longitudinal strain value.

The 2 groups did not differ concerning LV septum thickness at end-diastole, LV posterior wall thickness at end-diastole, LVEDV, LVESV, LVEF, peak mitral E wave velocity, peak mitral A wave velocity, mitral E/e′ ratio, peak S′ velocity, pulmonary artery systolic pressure, and TAPSE. The LV (GLS) value was significantly worse (less negative) in the post–COVID-19 group than in the control group (P=0.006). Pericardial effusion was present in 3 patients (7.5%) in the post–COVID-19 group.

Reproducibility

For conventional 2D/Doppler measurements, the coefficient of variation ranged from 4.2% to 6.3% for intraobserver variability and from 3.5% to 6.7% for interobserver variability. For LVGLS, the intra- and interobserver coefficients of variation were 5% and 4.7%, respectively.

DISCUSSION

In this study, LVGLS was measured using 2D-STE to assess LV function in 40 young adult patients following COVID-19 recovery at home presenting with persistent post-infection symptoms. The mean period after diagnosis with acute COVID-19 illness was 67 days (45–90 d), and the mean period after negative COVID-19 testing was 38.8 days (21–60 d). None of the patients had a previous history of cardiac disease. Ongoing dyspnea (47%), chest pain (23%), palpitations (20%), fatigue (55%), and joint pain (10%) were the post–COVID-19 symptoms reported in the present study. The principal finding of the current study was that despite normal resting LV 2D EF values, LVGLS was worse in the post–COVID-19 group than in the control group.

Persistent symptoms post–COVID-19 were identified in nearly 87% of severe cases that required hospitalization, with the most common symptoms being dyspnea and fatigue.[7] During the period of hospital stay, 46% of patients without pre-existing cardiac disease developed abnormalities in echocardiograms.[16] However, information regarding patients who do not require hospitalization is scarce.

The results of the current study indicated the presence of subclinical impairment in LV systolic function in non-hospitalized young adult patients with persistent post–COVID-19 symptoms.

Previous studies have shown that 2D-STE detects subclinical impairment of LV function in patients with normal 2D EF such

as hypertensive, diabetic, and ischemic heart diseases.[17–19] All these diseases lead to subendocardial fibrosis, which is responsible for longitudinal systolic dysfunction.[20] In the current study, we excluded patients with diabetes, hypertension, and ischemic heart disease. Moreover, the CT chest severity score was 8.7 (SD=4.7), indicating non-severe disease.[21]

Our findings offer an important insight into the possibility of cardiac affection in recovered non-severe COVID-19 patients. Previous studies have confirmed myocardial damage in hospitalized COVID-19 patients, and they have found a significant association between the disease severity and the extent to which LV function is impaired. Moreover, increased troponin and D-dimer levels are associated with greater impairments of LV function and poorer outcomes.[22,23] In a study evaluating LV function using 2D-STE in 100 hospitalized COVID-19 patients, LV function measured by LVGLS was worse in severe cases and patients with marked elevations in troponin and D-dimer.[24] In our study, recovered non-hospitalized patients had normal troponin and D-dimer levels, indicating a persistent effect of COVID-19 on myocardial function beyond the acute phase of the disease. This long-lasting effect of the SARS-CoV-2 virus on the cardiovascular system has been confirmed by cardiovascular magnetic resonance (CMR) in a cohort of 100 recovered patients. CMR was performed an average of 71 days after recovery, and cardiac involvement was detected in 78% of the patients. The most common form of abnormality was inflammation (60%), followed by local scar and pericardial involvement. Additionally, LVEF was lower in the recovered patients than in the healthy control group and the risk-factor matched control group (P<0.001). These changes were not related to the severity of COVID-19 or the pre-existing conditions. Of interest, patients with an EF value of less than 50% were sent for a myocardial biopsy, which showed only active lymphocyte infiltration with no evidence of the virus genome.[25] Cardiac affection in 148 severely ill hospitalized patients, including those who required mechanical ventilation, was assessed weeks after acute infection using CMR, which showed persistent localized inflammation with myocarditis late gadolinium enhancement (LGE) patterns in 27% of the patients with normal LV and RV function.[26] Still, when CMR was done earlier on 29 patients after recovery, the incidence of myocarditis LGE patterns rose to 45%.[27] In another retrospective study on 26 patients reporting cardiac symptoms after recovery from COVID-19, LGE was found in 8 patients (31%).[28]

These findings demonstrate that the inflammation process and the subsequent fibrosis are the main mechanisms of cardiac affection. Although our patients had a less severe form of the disease and without obvious cardiovascular risk factors, our data indicate the effect of inflammation on cardiac function. Brito et al[29] assessed 54 young athletes who tested positive for COVID-19, either symptomatic (n=38) or asymptomatic (n=16). The subjects had no complications after recovery. The results revealed that LVGLS was reduced (<16) in 24% of the patients (11% of the symptomatic group vs 13% of the asymptomatic group), while RV function parameters were normal in all the patients. This finding regarding RV function is concordant with our finding of normal RV function.

Another echocardiographic finding of our recovered COVID-19 patients was the presence of mild pericardial effusion in 7% of the patients. A previous meta-analysis detected pericardial effusion in the chest CT of 5% of patients with COVID-19.[30] The mechanism of pericardial affection remains

unclear. Indeed, is it the direct effect of the SARS-CoV-2 virus, or does effusion occur as part of systemic inflammation? Analysis of aspirated pericardial fluids was negative for the SARS-CoV-2 virus in most of the previous studies in the literature.[31,32] On the other hand, other serous spaces like the pleura were not affected in the CMR study of recovered COVID-19 patients with pericardial effusion.[29] Such findings also raise questions concerning the relationship between the findings and persistent symptoms in recovered COVID-19 patients. In addition, the question remains as to how to manage this type of mild pericardial effusion not requiring aspiration. Another query of note is the possible role of classic treatment modalities such as NSAIDs and corticosteroids in this group of patients.

Limitations

The salient limitation of the current investigation is its small sample size. Additionally, patients who required hospitalization or those who were completely asymptomatic were not included in the study. Moreover, the results could have been bolstered had routine CMR examinations been performed to detect evidence of myocardial inflammation.

CONCLUSIONS

The present study showed that in young adult patients, LVGLS was affected by COVID-19. These results indicate the need for further larger studies on the long-term effect of COVID-19 on LV function, which may have an impact on the treatment of these patients.

Disclosure: The authors have nothing to disclose with regard to commercial support.

Conflict of Interest: The authors declare that there is no conflict of interest.

REFERENCES

1. Guo T, Fan Y, Chen M, Wu X, Zhang L, He T, et al. Cardiovascular Implications of Fatal Outcomes of Patients With Coronavirus Disease 2019 (COVID-19). JAMA Cardiol 2020; 5:811–8. https://doi.org/10.1001/jamacardio.2020.1017.

2. Shi S, Qin M, Shen B, Cai Y, Liu T, Yang F, et al. Association of Cardiac Injury with Mortality in Hospitalized Patients with COVID-19 in Wuhan, China. JAMA Cardiol 2020; 5:802–10. https://doi.org/10.1001/jamacardio.2020.0950.

3. Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet 2020; 395:497–506. https://doi.org/10.1016/S0140-6736(20)30183-5.

4. Varga Z, Flammer AJ, Steiger P, Haberecker M, Andermatt R, Zinkernagel AS, et al. Endothelial cell infection and endotheliitis in COVID-19. Lancet 2020; 395:1417–8. https://doi.org/10.1016/S0140-6736(20)30937-5.

5. Yang J, Biery DW, Singh A, Divakaran S, DeFilippis EM, Wu WY, et al. Risk Factors and Outcomes of Very Young Adults Who Experience Myocardial Infarction: The Partners YOUNG-MI Registry. Am J Med 2020; 133:605-612.e1. https://doi.org/10.1016/j.amjmed.2019.10.020.

6. Tenforde MW, Kim SS, Lindsell CJ, Billig Rose E, Shapiro NI, Files DC, et al. Symptom Duration and Risk Factors for Delayed Return to Usual Health Among Outpatients with COVID-19 in a Multistate Health Care Systems Network — United States, March–June 2020. MMWR Morb Mortal Wkly Rep 2020; 69:993–8. https://doi.org/10.15585/mmwr.mm6930e1.

7. Carfì A, Bernabei R, Landi F. Persistent symptoms in patients after acute COVID-19. JAMA - J Am Med Assoc 2020; 324:603–5. https://doi.org/10.1001/jama.2020.12603.

8. Libby P, Lüscher T. COVID-19 is, in the end, an endothelial disease. Eur Heart J 2020; 41:3038–44. https://doi.org/10.1093/eurheartj/ehaa623.

9. Tops LF, Delgado V, Marsan NA, Bax JJ. Myocardial strain to detect subtle left ventricular systolic dysfunction. Eur J Heart Fail 2017; 19:307–13. https://doi.org/10.1002/ejhf.694.

10. Lang RM, Badano LP, Victor MA, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015; 28:1-39.e14. https://doi.org/10.1016/j.echo.2014.10.003.

11. Nagueh SF, Appleton CP, Gillebert TC, Marino PN, Oh JK, Smiseth OA, et al. Recommendations for the Evaluation of Left Ventricular Diastolic Function by Echocardiography. J Am Soc Echocardiogr 2009; 22:107–33. https://doi.org/10.1016/j.echo.2008.11.023.

12. Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, et al. Guidelines for the Echocardiographic Assessment of the Right Heart in Adults: A Report from the American Society of Echocardiography. Endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and . J Am Soc Echocardiogr 2010; 23:685–713. https://doi.org/10.1016/j.echo.2010.05.010.

13. Parasuraman S, Walker S, Loudon BL, Gollop ND, Wilson AM, Lowery C, et al. Assessment of pulmonary artery pressure by echocardiography-A comprehensive review. IJC Hear Vasc 2016; 12:45–51. https://doi.org/10.1016/j.ijcha.2016.05.011.

14. Voigt JU, Pedrizzetti G, Lysyansky P, Marwick TH, Houle H, Baumann R, et al. Definitions for a common standard for 2D speckle tracking echocardiography: consensus document of the EACVI/ASE/Industry Task Force to standardize deformation imaging. Eur Heart J Cardiovasc Imaging 2015;16:1–11. https://doi.org/10.1093/ehjci/jeu184.

15. Pan F, Ye T, Sun P, Gui S, Liang B, Li L. Time Course of Lung Changes at Chest CT during Recovery. Radiology 2020; 295:715–21.

16. Dweck MR, Bularga A, Hahn RT, Bing R, Lee KK, Chapman AR, et al. Global evaluation of echocardiography in patients with COVID-19. Eur Heart J Cardiovasc Imaging 2020; 21:949–58. https://doi.org/10.1093/ehjci/jeaa178.

17. Rosen BD, Saad MF, Shea S, Nasir K, Edvardsen T, Burke G, et al. Hypertension and smoking are associated with reduced regional left ventricular function in asymptomatic individuals: The Multi-Ethnic Study of Atherosclerosis. J Am Coll Cardiol 2006; 47:1150–8. https://doi.org/10.1016/j.jacc.2005.08.078.

18. Choi J-O, Cho SW, Song YB, Cho SJ, Song BG, Lee S-C, et al. Longitudinal 2D strain at rest predicts the presence of left main and three vessel coronary artery disease in patients without regional wall motion abnormality. Eur J Echocardiogr 2009;10:695–701. https://doi.org/10.1093/ejechocard/jep041.

19. Fonseca CG, Dissanayake AM, Doughty RN, Whalley GA, Gamble GD, Cowan BR, et al. Three-dimensional assessment of left ventricular systolic strain in patients with type 2 diabetes mellitus, diastolic dysfunction, and normal ejection fraction. Am J Cardiol 2004; 94:1391–5. https://doi.org/10.1016/j.amjcard.2004.07.143.

20. Kang SJ, Lim HS, Choi BJ, Choi SY, Hwang GS, Yoon MH, et al. Longitudinal Strain and Torsion Assessed by Two-Dimensional Speckle Tracking Correlate with the Serum Level of Tissue Inhibitor of Matrix Metalloproteinase-1, a Marker of Myocardial Fibrosis, in Patients with Hypertension. J Am Soc Echocardiogr 2008; 21:907–11. https://doi.org/10.1016/j.echo.2008.01.015.

21. Wasilewski PG, Mruk B, Mazur S, Półtorak-Szymczak G, Sklinda K, Walecki J. COVID-

19 severity scoring systems in radiological imaging – A review. Polish J Radiol 2020; 85:e361–8. https://doi.org/10.5114/pjr.2020.98009.

22. Tersalvi G, Vicenzi M, Calabretta D, Biasco L, Pedrazzini G, Winterton D. Elevated Troponin in Patients With Coronavirus Disease 2019: Possible Mechanisms. J Card Fail 2020; 26:470–5. https://doi.org/10.1016/j.cardfail.2020.04.009.

23. Zheng Z, Peng F, Xu B, Zhao J, Liu H, Peng J, et al. Risk factors of critical & mortal COVID-19 cases: A systematic literature review and meta-analysis. J Infect 2020; 81:e16–25. https://doi.org/10.1016/j.jinf.2020.04.021.

24. Baycan OF, Barman HA, Atici A, Tatlisu A, Bolen F, Ergen P, et al. Evaluation of biventricular function in patients with COVID-19 using speckle tracking echocardiography. Int J Cardiovasc Imaging 2020. https://doi.org/10.1007/s10554-020-01968-5.

25. Puntmann VO, Carerj ML, Wieters I, Fahim M, Arendt C, Hoffmann J, et al. Outcomes of Cardiovascular Magnetic Resonance Imaging in Patients Recently Recovered from Coronavirus Disease 2019 (COVID-19). JAMA Cardiol 2020; 5:1265–73. https://doi.org/10.1001/jamacardio.2020.3557.

26. Kotecha T, Knight DS, Razvi Y, Kumar K, Vimalesvaran K, Thornton G, et al. Patterns of myocardial injury in recovered troponin-positive COVID-19 patients assessed by cardiovascular magnetic resonance. Eur Heart J 2021; 42:1866–78. https://doi.org/10.1093/eurheartj/ehab075.

27. Knight DS, Kotecha T, Razvi Y, Chacko L, Brown JT, Jeetley PS, et al. COVID-19: Myocardial injury in survivors. Circulation 2020:1120–2. https://doi.org/10.1161/CIRCULATIONAHA.120.049252.

28. Huang L, Zhao P, Tang D, Zhu T, Han R, Zhan C, et al. Cardiac Involvement in Patients Recovered From COVID-2019 Identified Using Magnetic Resonance Imaging. JACC Cardiovasc Imaging 2020; 13:2330–9. https://doi.org/10.1016/j.jcmg.2020.05.004.

29. Brito D, Meester S, Yanamala N, Patel HB, Balcik BJ, Casaclang-Verzosa G, et al. High Prevalence of Pericardial Involvement in College Student Athletes Recovering From COVID-19. JACC Cardiovasc Imaging 2020. https://doi.org/10.1016/j.jcmg.2020.10.023.

30. Bao C, Liu X, Zhang H, Li Y, Liu J. Coronavirus Disease 2019 (COVID-19) CT Findings: A Systematic Review and Meta-analysis. J Am Coll Radiol 2020; 17:701–9. https://doi.org/10.1016/j.jacr.2020.03.006.

31. Fox K, Prokup JA, Butson K, Jordan K. Acute Effusive Pericarditis: A Late Complication of COVID-19. Cureus 2020; 12:8–13. https://doi.org/10.7759/cureus.9074.

32. Derveni V, Kaniaris E, Toumpanakis D, Potamianou E, Ioannidou I, Theodoulou D, et al. Acute life-threatening cardiac tamponade in a mechanically ventilated patient with COVID-19 pneumonia. IDCases 2020; 21:e00898. https://doi.org/10.1016/j.idcr.2020.e00898.