RESEARCH ARTICLE

DOI: 10.4274/ijca.2023.88598
Int J Cardiovasc Acad 2023;9(2):42-47

Evaluation of Right Ventricular Global Longitudinal Strain in COVID-19 Patients After Intensive Care Unit Discharge

Serhat Günlü[1], Abdulkadir Arpa[2], Adem Aktan[3], Tuncay Güzel[4], Raif Kılıç[5], Fethullah Kayan[1], Mehmet Ali Işık[3], Murat Çelikten[6], Bayram Arslan[7], Mehmet Zülkif Karahan[1]

[1]Department of Cardiology, Mardin Artuklu University Faculty of Medicine, Mardin, Turkey
[2]Clinic of Cardiology, Bismil State Hospital, Diyarbakır, Turkey
[3]Clinic of Cardiology, Mardin Training and Research Hospital, Mardin, Turkey
[4]Clinic of Cardiology, University of Health Sciences Turkey, Gazi Yaşargil Training and Research Hospital, Diyarbakır, Turkey
[5]Clinic of Cardiology, Private Memorial Hospital, Diyarbakır, Turkey
[6]Clinic of Family Medicine, University of Health Sciences Turkey, Gazi Yaşargil Training and Research Hospital, Diyarbakır, Turkey
[7]Clinic of Cardiology, Ergani State Hospital, Diyarbakır, Turkey

Abstract

Background and Aim: Using two-dimensional speckle tracking echocardiography (2D-STE), the ventricular functions of hospitalized coronavirus disease-2019 (COVID-19) patients were assessed. However, there is limited information about cardiac functions in the first year after recovery from the intensive care unit (ICU). This research aims to assess the right ventricular functions of COVID-19 patients and their changes within the first year after ICU discharge using 2D-STE.

Materials and Methods: The study was conducted prospectively. The study included 68 consecutive patients and 70 control patients. Echocardiography was performed in the ICU and the first year after discharge from the hospital. Right ventricular global longitudinal strain (RVGLS) was measured using the 2D-STE method.

Results: The mean age of the study group was 48.67±8.10 and 37 (54.4%) patients were males. There were no substantial differences across the groups, including age, gender, body mass index, heart rate, diabetes, dyslipidemia, and smoking ($P > 0.05$). A substantially significant positive correlation was detected between right ventricular dimension (RAD) ($r = 0.644$, $P < 0.001$), right ventricular diastolic dimension (RVDD) ($r = 0.573$, $P < 0.001$), ferritin ($r = 0.454$, $P < 0.001$), D-dimer ($r = 0.305$, $P = 0.011$) values and RVGLS in the in-hospital and after-discharge first-year groups. The RVGLS values of the control, in-hospital, and after-discharge first-year groups were -20.36±3.06, -16.98±3.78, and -17.58±6.45, indicating a statistically significant difference across the groups ($P < 0.001$). Tricuspid annular plane systolic excursion was higher in the control group ($P < 0.05$).

Conclusion: RVGLS was found to be depressed during the in-hospital period and showed no improvement in the 1 year post discharge.

Keywords: Echocardiography, strain, right ventricle, speckle-tracking, COVID-19

To cite this article: Günlü S, Arpa A, Aktan A, Güzel T, Kılıç R, Kayan F, Işık MA, Çelikten M, Arslan B, Karahan MZ. Int J Cardiovasc Acad 2023;9(2):42-47

Address for Correspondence: MD. Serhat Günlü, Department of Cardiology, Mardin Artuklu University Faculty of Medicine, Mardin, Turkey
E-mail: serhat8086@hotmail.com
ORCID ID: orcid.org/0000-0001-6985-6112

Received: 07.04.2023
Revised: 03.07.2023
Accepted: 05.07.2023
Published Online: 07.07.2023

INTRODUCTION

Coronavirus disease-2019 (COVID-19), which has turned into a widespread epidemic worldwide, first affects the respiratory system.[1] Although we know that it directly affects the heart, it usually causes cardiac impairment secondary to the involvement of other organs.[2] Recent investigations have revealed that the cardiac involvement may result in pericarditis, myocarditis, cardiac tamponade, and myocardial infarction.[3] The most common cause of in-hospital mortality in COVID-19 patients is ventricular dysfunction.[4]

The right ventricle (RV) is more likely to be damaged than the left ventricle (LV) due to rising RV afterload because COVID-19 primarily affects the lungs.[5] In previous research, individuals with acute respiratory distress syndrome (ARDS) and respiratory failure were found to have RV dysfunction.[6] Standard echocardiographic measures may not be able to detect subclinical RV abnormalities, which makes diagnosis and risk categorization difficult. The most objective and sensitive examination of RV systolic dysfunction is provided by two-dimensional speckle tracking echocardiography (2D-STE).[7] Thus, right ventricular global longitudinal strain (RVGLS) has been examined for predicting mortality in hospitalized patients. In COVID-19 patients, evaluation of RV function with 2D-STE in the first year after intensive care unit (ICU) discharge has not been published.

This study aims to investigate whether improving RV functions or not by measuring RVGLS with 2D-STE at the end of the first year after discharge from the ICU.

MATERIALS AND METHODS

The selection of participants

The study was conducted prospectively. The RVGLS values of 68 consecutive patients who met the inclusion criteria from COVID patients admitted to the critical care unit between December 2020 and December 2021 were recorded, and RVGLS values were reanalyzed after a 1 year follow-up between December 2021 and December 2022. The study included 70 healthy volunteers as a control group. Clinical conditions affecting RV strain such as structural heart disease, hypertension, chronic liver or kidney disease, pulmonary embolism, malignancy, history of asthma and pulmonary hypertension, obstructive pulmonary disease, and previous COVID were excluded from the study. Additionally, patients who had COVID of within the first year after discharge and who died were not included in the study.

Study protocol

Demographic characteristics, echocardiographic measurements, and blood samples of patients with COVID-19 hospitalized in intensive care were obtained from medical records. Complete blood cell analysis, C-reactive protein (CRP), ferritin, hs-TnT, D-dimer, and echocardiography were performed for all patients in the first year after discharge. Blood samples were examined from the control group while echocardiography was performed on the same day. All patients underwent bedside transthoracic echocardiographic tests using the Philips EPIQ 7C device (Andover, Massachusetts). The size of the right atrium and RV was assessed using a 4-chamber apical view. On M-mode imaging, tricuspid annular plane systolic excursion (TAPSE) was measured as the systolic displacement of the tricuspid lateral annulus. Using PW tissue Doppler imaging, the RV myocardial performance index (RVMPI) was measured. (RV end-diastolic area RV end-systolic area)/end-diastolic area 100% was used to determine RV fractional area change (RVFAC). Pulmonary artery systolic pressure (sPAP) was measured using the peak velocity of the tricuspid regurgitation jet and the size and collapsibility of the inferior vena cava to calculate right atrial pressure.[8] In line with recommendations from the American Society of Echocardiography and the European Association of Cardiovascular Imaging[9], 2D-STE was applied to assess longitudinal systolic strain (Figure 1). Images were obtained in the four (4C)-chamber views at 70-100 frames per second from the end of expiration and were evaluated blindly by two independent specialists.

Ethical statement

This study was approved by the Clinical Research Ethics Committee of the University of Health Sciences Turkey, Gazi Yaşargil Training and Research Hospital (no: 133, date: 22.07.2022). It adhered to the Declaration of Helsinki's ethical guidelines for human experimentation (2013).

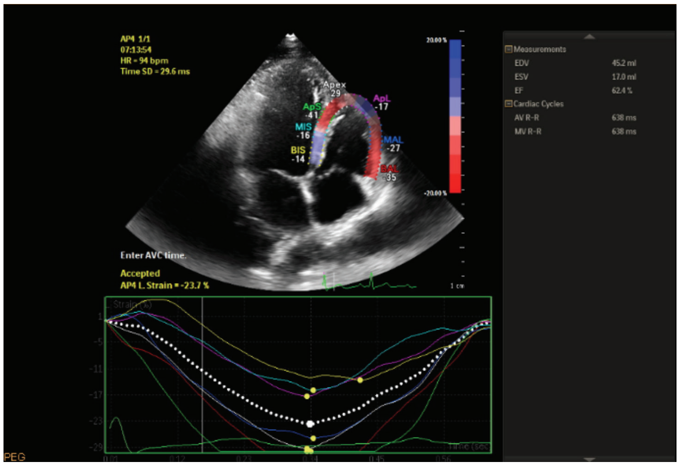

Figure 1: Measurement of right ventricular global longitudinal strain

Statistical analysis

IBM SPSS 24.0 version analyzed the data. Student's t-test or One-Way analysis of variance was used for normally distributed data and Mann-Whitney U or Kruskal-Wallis tests was used for non-normally distributed data. The chi-square or Fisher's exact test was used to compare categorical variables reported as frequency (%). The correlation between RVGLS and right ventricular dimension (RAD), RVDD, TAPSE, sPAP, D-dimer, CRP, and ferritin levels was determined using Pearson or Spearman correlation analysis. A $P < 0.05$ signified statistical validity.

RESULTS

A total of 138 individuals, 68 of whom recovered from COVID-19 and 70 controls, were enrolled in the study. The average age of the study group was 48.67 ± 8.10 and 37 (54.4%) patients were male. There were no substantial differences across the groups, including age, gender, BMI, HR, diabetes, dyslipidemia, and smoking ($P > 0.05$, Table 1).

The WBC, CRP, D-dimer, and ferritin levels were higher in the study group than in the controls ($P < 0.001$). In the study group, 7 (10.3%) patients had ARDS, and 6 (8.8%) patients were administered immune-modulators. High-flow oxygen was given to 9 (13.2%) patients. Non-invasive mechanical ventilation and IMV were performed on 16 (23.5%) and 7 (10.3%) patients, respectively. In the echocardiographic parameters, RAD, RVSD, RVDD, RVMPI, RVGLS, and sPAP were higher in the in-hospital and after-discharge first-year groups ($P < 0.05$, Table 2). E/A ratio was lower and LV ejection fraction was higher in the control group ($P > 0.05$).

The RVGLS values of the control, in-hospital, and after-discharge first-year groups were -20.36 ± 3.06, -16.98 ± 3.78, and -17.58 ± 6.45, indicating a statistically significant difference across the

Table 1: Clinical characteristics and laboratory parameters of patients

Parameters	The control group *n = 70*	The study group *n = 68*	*P*-value
Age (years)	47.24±8.45	48.67±8.10	0.311
Gender, male, n (%)	33 (47.1)	37 (54.4)	0.393
BMI (kg/m^2)	23.67±4.24	24.31±4.54	0.396
HR (beats/min)	86.0±8.75	89.2±13.23	0.092
Diabetes mellitus, n (%)	15 (21.4)	19 (27.9)	0.375
Dyslipidemia, n (%)	6 (8.6)	8 (11.8)	0.534
Smoking, n (%)	19 (27.1)	16 (23.5)	0.626
Laboratory findings			
Hemoglobin (g/dL)	13.67±2.03	13.09±2.40	0.124
WBC (10^3/µl)	8.26±0.77	11.93±4.23	<0.001
Lymphocytes (10^3/µl)	2.84±0.78	2.79±1.48	0.238
Neutrophil (10^3/µl)	6.02±7.89	6.35±1.48	0.094
Increased troponin, n (%)	-	22 (32.4)	-
Glucose (mg/dL)	88.45±8.56	92.29±23.28	0.199
CRP (mg/L)	0.3 (0.08)	2.1 (2.51)	<0.001
D-dimer (ng/mL)	238.5 (20.0)	810 (260.2)	<0.001
Ferritin (mL/ng)	181.5 (35.5)	495.5 (31.2)	<0.001
ALT (U/L)	21.54±8.33	21.89±8.63	0.807
AST (U/L)	23.68±5.22	24.51±9.61	0.529
Treatment			
Immune modulator, n (%)	-	6 (8.8)	-
Highflow, n (%)	-	9 (13.2)	-
NIMV, n (%)	-	16 (23.5)	-
IMV, n (%)	-	7 (10.3)	-
ARDS, n (%)	-	7 (10.3)	-

Data are expressed as appropriate as mean ± standard deviation and median (interquartile range). BMI: Body mass index, HR: Heart rate, WBC: White blood cell, CRP: C-reactive protein, ALT: Alanine transaminase, AST: Aspartate transaminase, NIMV: Non-invasive mechanical ventilation, IMV: Invasive mechanical ventilation, ARDS: Acute respiratory distress syndrome groups ($P < 0.001$). RVFAC was not significant across the groups ($P > 0.05$). TAPSE was higher in the control group ($P < 0.05$). There were no significant differences between the in-hospital and after-discharge first years in terms of echocardiographic parameters ($P > 0.05$). However, sPAP was statistically different between the in-hospital and after-discharge first-year groups ($P = 0.031$). On the other hand, RVSD and RVMPI were statistically significant between the in-hospital and control groups ($P = 0.044$, $P = 0.048$). There was an association between RVGLS and RAD, RVDD, TAPSE, sPAP, D-dimer, CRP, and ferritin levels. A positive correlation was detected between RAD ($r = 0.644$, $P < 0.001$), RVDD ($r = 0.573$, $P < 0.001$), ferritin ($r = 0.454$, $P < 0.001$), D-dimer ($r = 0.305$, $P = 0.011$) values and the in-hospital group. Likewise, a negative correlation was detected between TAPSE ($r = -0.511$, $P < 0.001$), CRP ($r = -0.315$, $P = 0.009$) and the in-hospital group (Table 3).

In addition, a positive correlation was determined between RAD ($r = 0.409$, $P = 0.001$), RVDD ($r = 0.268$, $P = 0.027$), Ferritin ($r = 0.495$, $P < 0.001$), D-dimer ($r = 0.388$, $P = 0.001$) and after-discharge first-year group.

DISCUSSION

This study evaluated right ventricular functions with 2D-STE in the first year in ICU discharge. After one year of follow-up, no statistically significant RV improvement was observed in RAD, RVSD, RVDD, TAPSE, and RVGLS parameters ($P > 0.05$). On the contrary, the sPAP value increased even more ($P = 0.031$).

Viral infections provoke an intense inflammatory reaction in the body. CRP, ferritin, and D-dimer were indicators of the systemic inflammation of COVID-19. CRP was found to be high in 75-90% of patients with severe COVID-19 involvement.[10] A value greater than 10 indicates the widespread involvement. In Chinese studies by Guan et al.[11], 46% of individuals had raised D-dimer values (>0.5 mg/L). Huang et al.[12] discovered that COVID-19 hospitalized in the ICU had a greater D-dimer level than those who did not receive ICU care. Another acute phase reactant is serum ferritin.[13] In Zhou et al.[14] retrospective research, blood ferritin levels were significantly higher in non-survivors than in survivors. Mahmoud-Elsayed et al.[15] reported that inflammation parameters predicted RV dysfunction independently of left ventricular dysfunction in patients with

Table 2: Comparison of right ventricular echocardiographic parameters between the groups

	The control group (A) *n = 70*	The study group (In-hospital) (B) *n = 68*	The study group (After discharge first year) (C) *n = 68*	P (A-B)	P (B-C)	P (A-C)
RAD (mm)	3.59±0.45	3.81±0.72	3.70±0.67	0.041	0.305	0.022
RVSD (mm)	2.77±0.50	2.96±0.73	2.92±0.57	0.048	0.461	0.166
RVDD (mm)	3.75±0.59	4.01±0.74	3.81±0.55	0.019	0.072	0.049
RVFAC (%)	53.18±8.91	51.69±8.92	52.76±9.15	0.083	0.287	0.605
RVMPI	0.47±0.07	0.50±0.10	0.49±0.07	0.044	0.395	0.130
RVGLS (%)	-20.36±3.06	-16.98±3.78	-17.58±6.45	<0.001	0.453	<0.001
TAPSE (mm)	2.20±0.14	2.08±0.30	2.10±0.30	0.007	0.692	0.014
sPAP (mmHg)	17.20±4.53	26.60±7.11	24.70±3.20	<0.001	0.031	<0.001
E/A ratio	1.5±0.52	1.7±0.91	1.6±0.58	0.168	0.387	0.423
LVEF (%)	65.1±3.9	64.2±7.7	64.6±5.5	0.412	0.197	0.384

Values are mean ± standard deviation, n (%), or median (interquartile range). RAD: Right atrium dimension, RVSD: Right ventricular systolic dimension, RVDD: Right ventricular diastolic dimension, RVFAC: Right ventricular fractional area change, RVMPI: Right ventricular myocard performance index, RVGLS: Right ventricular global longitudinal strain, TAPSE: Tricuspid annular plane systolic excursion, sPAP: Systolic pulmonary artery pressure, LVEF: Left ventricular ejection fraction

Table 3: Correlation of right ventricular global longitudinal strain with parameters

		RAD	RVDD	TAPSE	sPAP	CRP	Ferritin	D-dimer
RVGLS In-hospital	*r*	0.644	0.573	-0.511	-0.200	-0.315	0.454	0.305
	P	**<0.001**	**<0.001**	**<0.001**	0.101	**0.009**	**<0.001**	**0.011**
RVGLS After discharge	*r*	0.409	0.268	-0.229	0.160	-0.081	0.495	0.388
	P	**0.001**	**0.027**	0.060	0.193	0.514	**<0.001**	**0.001**
RVGLS Controls	*r*	-0.403	-0.026	0.059	0.331	-0.011	0.072	-0.306
	P	**0.001**	0.830	0.628	**0.005**	0.929	0.556	**0.010**

RVGLS: Right ventricular global longitudinal strain, RAD: Right atrium dimension, RVDD: Right ventricular diastolic dimension, TAPSE: Tricuspid annular plane systolic excursion, sPAP: Systolic pulmonary artery pressure, CRP: C-reactive protein

COVID-pneumonia. Although these parameters were associated with mortality in many meta-analysis studies, the values were mostly associated with the severity of the disease in our study.[16] Qeadan et al.[17] obtained results similar to the outcomes of our study.

Right ventricular dysfunction has been reported in echocardiography of COVID-19 patients.[18] In a large-scale study of 69 countries, Dweck et al.[19] noted that a quarter of all patients had right ventricular dysfunction, with the vast majority of these patients exhibiting severe symptoms. The RV dilates due to an increase in afterload. This increases RAD, RVSD, and RVDD. In a meta-analysis, Corica et al.[20] reported that 1 in 5 patients had increased right ventricular diameters. The vast majority of them consisted of ICU patients. In accordance with earlier research and Chotalia et al.'s[21] findings, the patient's right ventricular diameters and sPAP values were found to be increased in our study.

TAPSE, RVFAC, and RVMPI are conventional measures of the right ventricular ejection fraction. According to Baycan et al.[22] research, there was no difference in RVFAC and RVMPI between the control and study groups. Li et al.[23] found lower TAPSE and RVFAC values lower and higher RVMPI in COVID patients compared with the control group. Günay et al.[24] found lower RVFAC values in recovery patients. Catena et al.[25] reported that there was no difference in right ventricular conventional parameters between the in-hospital and post-discharge groups. The same results were obtained in our study ($P > 0.05$).

Unlike conventional methods, RVGLS is an independent predictor of COVID involvement and is a superior method because it is measured independently of angle.[26] Using the RVGLS measure, Turan et al.[27] revealed right ventricular impairment following recovery in asymptomatic and mildly symptomatic individuals. Carluccio et al.[28] demonstrated that this method provides prognostic information for right ventricular failure in patients with preserved TAPSE and RVMPI measurements. Ozer et al.[29] reported that TAPSE and RVFAC values were normal in the echocardiography performed at the 3rd month after discharge from the ICU, and only deterioration in RVGLS values. In our study, although RVGLS values were lower than those in the control group, no improvement was found in RVGLS values in the first year in discharge. In addition, a correlation has been found between RVGLS and inflammatory markers.[30] In this trial, a positive correlation was found between RVGLS measurement, which is a sensitive indicator of right ventricular subclinical involvement, and CRP, D-dimer, and ferritin. Increased CRP, D-dimer and ferritin levels at the hospital admission and to recovery were related to RVGLS impairment, supporting this conclusion.

Study limitations

Our study population was small. Previously, detailed echocardiography measurements of the patients were not available in the records. Due to technical limitations, 3D-STE and cardiac MRI were not performed on the patients.

CONCLUSION

In this study, the results showed that impaired RVGLS values did not improve at the first year of follow-up. The long-term effects of COVID-19 infection on right ventricular function are unknown, so prospective studies with longer follow-ups are required.

Ethics

Ethics Committee Approval: This study was approved by the Clinical Research Ethics Committee of the University of Health Sciences Turkey, Gazi Yaşargil Training and Research Hospital (no: 133, date: 22.07.2022).

Informed Consent: Prospective study.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices: S.G., A.A., A.Ak., R.K., M.A.I., M.Z.K., Concept: S.G., A.A., T.G., F.K., M.Ç., M.Z.K., Design: S.G., A.Ak., R.K., B.A., M.Z.K., Data Collection or Processing: S.G., T.G., M.Z.K., Analysis or Interpretation: S.G., A.A., M.A.I., M.Ç., M.Z.K., Literature Search: S.G., A.Ak., F.K., B.A., M.Z.K., Writing: S.G., M.A.I., M.Z.K.

Conflict of Interest: No conflict of interest was declared by the author.

Financial Disclosure: The author declared that this study received no financial support.

REFERENCES

1. Zhu N, Zhang D, Wang W, Li X, Yang B, Song J, *et al*. A novel coronavirus from patients with pneumonia in China 2019. N Engl J Med 2020;382:727-33.
2. Repessé X, Charron C, Vieillard-Baron A. Right ventricular failure in acute lung injury and acute respiratory distress syndrome. Minerva Anestesiol 2012;78:941-8.
3. Çanga A. Late Cardiovascular Events in Covid-19. YIU Saglik Bil Derg 2022;3:21-5.
4. 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.
5. Tryfou ES, Kostakou PM, Chasikidis CG, Kostopoulos VS, Serafetinidis II, Ferdianaki EK, *et al*. Biventricular myocardial function in Covid-19 recovered patients assessed by speckle tracking echocardiography: a prospective cohort echocardiography study. Int J Cardiovasc Imaging 2021;38:995-1003.

6. Carluccio E, Biagioli P, Alunni G, Murrone A, Zuchi C, Coiro S, *et al*. Prognostic value of right ventricular dysfunction in heart failure with reduced ejection fraction: superiority of longitudinal strain over tricuspid annular plane systolic excursion. Circ Cardiovasc Imaging 2018;11:e006894.

7. Longobardo L, Suma V, Jain R, Carerj S, Zito C, Zwicke D, *et al*. Role of Two-Dimensional Speckle-Tracking Echocardiography Strain in the Assessment of Right Ventricular Systolic Function and Comparison with Conventional Parameters. J Am Soc Echocardiogr 2017;30:937-46.

8. Lang RM, Badano LP, Mor-Avi V, Aflalo 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. Eur Heart J Cardiovasc Imaging 2015;16:233-70.

9. 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 and the Canadian society of echocardiography. J Am Soc Echocardiogr 2010;23:685-713.

10. Lippi G, Plebani M. Laboratory abnormalities in patients with COVID-2019 infection. Clin Chem Lab Med 2020;58:1131-4.

11. Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, *et al*. Clinical Characteristics of Coronavirus Disease 2019 in China. N Engl J Med 2020;382:1708-20.

12. 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.

13. Wu C, Chen X, Cai Y, Xia J, Zhou X, Xu S, *et al*. Risk Factors Associated with Acute Respiratory Distress Syndrome and Death in Patients with Coronavirus Disease 2019 Pneumonia in Wuhan, China. JAMA Intern Med 2020;180:934-943.

14. Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, *et al*. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet 2020;395:1054-62.

15. Mahmoud-Elsayed HM, Moody WE, Bradlow WM, Khan-Kheil AM, Senior J, Hudsmith LE, *et al*. Echocardiographic fndings in patients with COVID-19 pneumonia. Can J Cardiol 2020;36:1203-7.

16. Huang I, Pranata R, Lim MA, Oehadian A, Alisjahbana B. C-reactive protein, procalcitonin, D-dimer, and ferritin in severe coronavirus disease-2019: a meta-analysis. Ther Adv Respir Dis 2020;14:1753466620937175.

17. Qeadan F, Tingey B, Gu LY, Packard AH, Erdei E, Saeed AI. Prognostic Values of Serum Ferritin and D-Dimer Trajectory in Patients with COVID-19. Viruses 2021;13:419.

18. Szekely Y, Lichter Y, Taieb P, Banai A, Hochstadt A, Merdler I, *et al*. The spectrum of cardiac manifestations in coronavirus disease 2019 (COVID-19)—a systematic echocardiographic study. Circulation 2020;142:342-53.

19. 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.

20. Corica B, Marra AM, Basili S, Cangemi R, Cittadini A, Proietti M, *et al*. Prevalence of right ventricular dysfunction and impact on all-cause death in hospitalized patients with COVID-19: a systematic review and meta-analysis. Sci Rep 2021;11:17774.

21. Chotalia M, Ali M, Alderman JE, Kalla M, Parekh D, Bangash MN, *et al*. Right Ventricular Dysfunction and Its Association With Mortality in Coronavirus Disease 2019 Acute Respiratory Distress Syndrome. Crit Care Med 2021;49:1757-68.

22. 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 2021;37:135-44.

23. Li Y, Li H, Zhu S, Xie Y, Wang B, He L, *et al*. Prognostic value of right ventricular longitudinal strain in patients with COVID-19. JACC Cardiovasc Imaging 2020;13:2287-99.

24. Günay N, Demiröz Ö, Kahyaoğlu M, Başlılar Ş, Aydın M, Özer MÇ, *et al*. The effect of moderate and severe COVID-19 pneumonia on short-term right ventricular functions: a prospective observational single pandemic center analysis. Int J Cardiovasc Imaging 2021;37:1883-90.

25. Catena C, Colussi G, Bulfone L, Da Porto A, Tascini C, Sechi LA. Echocardiographic Comparison of COVID-19 Patients with or without Prior Biochemical Evidence of Cardiac Injury after Recovery. J Am Soc Echocardiogr 2021;34:193-5.

26. Stockenhuber A, Vrettos A, Androshchuk V, George M, Robertson C, Bowers N, *et al*. A pilot study on right ventricular longitudinal strain as a predictor of outcome in COVID-19 patients with evidence of cardiac involvement. Echocardiography 2021;38:222-9. Erratum in: Echocardiography. 2021 May 24.

27. Turan T, Özderya A, Şahin S, Konuş AH, Kul S, Akyüz AR, *et al*. Left ventricular global longitudinal strain in low cardiac risk outpatients who recently recovered from coronavirus disease 2019. Int J Cardiovasc Imaging 2021;37:2979-89.

28. Carluccio E, Biagioli P, Alunni G, Murrone A, Zuchi C, Coiro S, *et al*. Prognostic Value of Right Ventricular Dysfunction in Heart Failure With Reduced Ejection Fraction: Superiority of Longitudinal Strain Over Tricuspid Annular Plane Systolic Excursion. Circ Cardiovasc Imaging 2018;11:e006894.

29. Ozer PK, Govdeli EA, Baykiz D, Karaayvaz EB, Metetalibeyoglu A, Catma Y, *et al*. Impairment of right ventricular longitudinal strain associated with severity of pneumonia in patients recovered from COVID-19. Int J Cardiovasc Imaging 2021;37:2387-97.

30. Park JF, Banerjee S, Umar S. In the eye of the storm: the right ventricle in COVID-19. Pulm Circ 2020;10:2045894020936660.