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Prognostic value of right ventricular strain pattern on ECG in COVID-19 patients

Hasan Ali Barman a,b,⁎, Adem Atici c, Irfan Sahin d, Omer Dogan a, Onur Okur e, Sevil Tugrul d, Ilker Avci f, Mustafa Taner Yildirim g, Baris Gunog r f, Sait Mesut Dogan a

a Istanbul University-Cerrahpaşa, Institute of Cardiology, Department of Cardiology, Istanbul, Turkey
b University of Health Sciences, Okmeydani Training and Research Hospital, Department of Cardiology, Istanbul, Turkey
c Istanbul Medeniyet University, Faculty of Medicine, Gazipe Training and Research Hospital, Department of Cardiology, Istanbul, Turkey
d University of Health Sciences, Bagcilar Training and Research Hospital, Department of Cardiology, Istanbul, Turkey
e University of Health Sciences, Okmeydani Training and Research Hospital, Department of Anesthesiology and Intensive Care, Istanbul, Turkey
f University of Health Sciences, Dr. Siyami Ersek Training and Research Hospital, Department of Cardiology, Istanbul, Turkey
g University of Health Sciences, Okmeydani Training and Research Hospital, Department of Infectious Diseases and Clinical Microbiology, Istanbul, Turkey

ARTICLE INFO

Article history:
Received 16 March 2021
Received in revised form 11 May 2021
Accepted 14 May 2021

Keywords:
Electrocardiography
Prognosis
COVID-19
Right ventricular strain

ABSTRACT

Objective: COVID-19 spread worldwide, causing severe morbidity and mortality and this process still continues. The aim of this study to investigate the prognostic value of right ventricular (RV) strain in patients with COVID-19.

Methods: Consecutive adult patients admitted to the emergency room for COVID-19 between 1 and 30 April were included in this study. ECG was performed on hospital admission and was evaluated as blind. RV strain was defined as in the presence of one or more of the following ECG findings: complete or incomplete right ventricular branch block (RBBB), negative T wave in V1-V4 and presence of S1Q3T3. The main outcome measure was death during hospitalization. The relationship of variables to the main outcome was evaluated by multivariable Cox regression analysis.

Results: A total of 324 patients with COVID-19 were included in the study; majority of patients were male (187, 58%) and mean age was 64.2 ± 14.1. Ninety-five patients (29%) had right ventricular strain according to ECG and 66 patients (20%) had died. After a multivariable survival analysis, presence of RV strain on ECG (OR: 4.385, 95% CI: 2.226–8.638, p < 0.001), high-sensitivity troponin I (hs-TnI), d-dimer and age were independent predictors of mortality.

Conclusion: Presence of right ventricular strain pattern on ECG is associated with in hospital mortality in patients with COVID-19.

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1. Introduction

The new coronavirus (SARS-CoV-2), which emerged towards the end of 2019, turned into a pandemic and caused serious effects on health and economy systems all over the world [1,2]. While some cases lead to asymptomatic or mild symptoms, in some cases the infection may progress to the lower respiratory tract, resulting in pneumonia, acute respiratory distress syndrome (ARDS) and, in the last stage, multiple organ failure, resulting in death [3,4]. The most important cause of mortality in COVID-19 patients is lung involvement. The virus infects cells, especially by connecting to the mainly expressed angiotensin converting enzyme-2 (ACE-2) receptor in lung tissue [5,6]. It is thought that COVID-19 infection harms many organs with direct and/or excessive immune response [4]. Many studies have reported that cardiac involvement is a sign of poor prognosis [3,4,7]. In a study examining right ventricular (RV) strain by echocardiography in COVID-19 patients, strain values were shown to be associated with mortality [8].

Electrocardiography (ECG) is a bedside diagnosis and fast diagnostic method. Due to the arrhythmic effects of drugs used in treatment in patients diagnosed with COVID-19, ECG is used as part of the baseline assessment [9]. Some ECG parameters, such as the right ventricular strain pattern, have been associated with obstruction of the pulmonary circulation and overload of the right ventricular pressure [10-12]. Prognostic significance of right ventricular strain on ECG has been demonstrated in patients with pulmonary embolism [11,13]. To our knowledge no

https://doi.org/10.1016/j.ajem.2021.05.039
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previous studies investigated the prognostic significance of RV strain detected in ECG in patients with COVID-19.

The aim of this study is to evaluate the relationship between RV strain pattern and mortality in ECG in COVID-19 patients.

2. Methods

For this single-center study, we retrospectively identified all consecutively hospitalized patients between April 1 and April 30, 2020 diagnosed with COVID-19 by real-time reverse transcription-polymerase chain reaction (RT-PCR). Patients with known cardiomyopathy, pulmonary hypertension, history of heart failure, history of severe valvular disease, a prior documented episode of pulmonary embolism, and a history of severe chronic obstructive pulmonary disease (COPD) were excluded. Based on these criteria, 61 patients were excluded from the study and thus a total of 324 patients were included in the analysis. Demographic characteristics of all patients such as gender, age, smoking, known hyperlipidemia, hypertension, diabetes, were recorded from medical records. This research presented no more than minimal risk to participants, thus informed consents were not obtained from individuals.

Laboratory findings; creatinine, sodium, potassium, glucose, high-sensitivity troponin I (hs-TnI), d-dimer, hemoglobin, white blood cells (WBC), procalcitonin and C-reactive protein (CRP) levels were recorded, which were analyzed from the blood samples collected from the patient on admission. The study complies with the Declaration of Helsinki, and the trial protocol was approved by the local ethics committee and Ministry of Health.

2.1. Electrocardiographic evaluation

A 12-lead admission ECG was obtained on hospital admission from all patients before any treatment was started. All ECGs (filter range 0.5 Hz to 150 Hz, AC filter 60 Hz, 25 mm/s, 10 mm/mV) were analyzed by 2 independent cardiologist according to the modified Minnesota criteria, who were blinded to the study design and clinical data. ST depressions, at least 1 mm or more horizontal and/or downsloping ST depression (in DI, DII, aVL, aVF, V1-V6 derivations) seen after point J was considered. Right ventricular branch block (RBBB), defined as broad QRS > 120 ms, rSR’ pattern in V1–3 (‘M-shaped’ QRS complex), wide, slurred S wave in the lateral leads (I, aVF, V5–6). Acute right ventricular strain was defined when at least one of the following patterns was found on ECG: [1] presence of S1Q3T3; [2] presence of complete or incomplete RBBB; [3] T wave inversions in the precordial leads (V1–V3) [14-16]. S1Q3T3 subtypes are S1Q3, S1rSr’3 and S1S2S3. T_{NEJ-V2} defined as T wave inversion in V2 or V3. Clockwise rotation of the QRS vector in the precordial leads (CLOCKROT) defined as R = S in V4, V5 or V6. The criteria for the diagnosis of Qt in V1 were the presence of a prominent Q wave of ≥0.2 mV and a ventricular depolarisation <120 ms. ST_{POS-V1} was defined as ST elevation in V1 ≥ 0.1 mV.

According to the World Health Organization (WHO) interim guidance, the diagnosis of COVID-19 is based on real-time RT-PCR test. SARS-CoV-2 RNA was detected by real-time RT-PCR method in the Public Health Microbiology Reference Laboratory of the Ministry of Health. Acute cardiac injury was defined as hs-TnI serum levels above the 99th percentile upper reference limit [17]. Systemic inflammatory response syndrome (SIRS) score is the systemic response of the organism to a variety of severe clinical situations. SIRS is defined by two or more of the following conditions: body temperature > 38 °C or < 36 °C; heart rate > 90 beats per minute; respiratory rate ≥ 20 breaths per minute or PaCO2 < 32 mmHg; and WBC count ≥12,000/cu mm, <4000/cu mm, or >10% immature (band) forms [18]. The primary end point was a composite of death for any cause during in-hospital stay. Patients were compared according to the presence of RV strain.

2.2. Statistical analysis

All statistical tests were conducted using the Statistical Package for the Social Sciences 19.0 for Windows (SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov test was used to analyze normality of the data. Continuous data are expressed as mean ± SD, and categorical data are expressed as percentages. Fisher Exact/or Chi-square test were used to assess differences in categorical variables between groups. Student’s t-test or Mann Whitney U test was used to compare unpaired samples as needed. The univariate effects of type of age, gender, hyper tension (HT), diabetes mellitus (DM), creatinine, d-dimer, CRP, procalcitonin, hs-TnI, RV strain, heart rate, ST depression, T wave inversion and ST elevation in V1 on ECG in COVID-19 patients was investigated using the log rank test. The possible factors identified with univariate analyses were further entered into the Cox regression analysis, with backward selection, to determine independent predictors of mortality. The proportional hazards assumption and model fit was assessed by means of residual (Schoenfeld and Martingale) analysis. Cumulative survival curves were derived according to the Kaplan-Meier method and differences between curves were analyzed on log-rank statistics. Significance was assumed at a 2-sided p < 0.05.

3. Results

Sixty-six of 324 COVID-19 patients included in the study are the non-survivor group and their clinical and demographic characteristics are shown in Table 1. When patients are grouped as the non-survivor group and the survivor group; while there was no statistically significant difference between the groups in terms of gender, the average

### Table 1

| Characteristic | Non-survivor (n = 66) | Survivor (n = 258) | p |
|---------------|-----------------------|--------------------|---|
| Age (years)   | 67.9 ± 13.3           | 60.4 ± 14.9        | <0.001|
| Male gender, n(%) | 40 (60%)           | 147 (57%)          | 0.594 |
| Body mass index (kg/m²) | 27.2 ± 6.2        | 26.8 ± 5.4         | 0.554 |
| Chronic medical illness – n (%) | Hypertension | 37 (56%) | 129 (50%) | 0.379 |
| Diabetes mellitus | 18 (27%)         | 66 (25%)           | 0.780 |
| Hyperlipidemia | 12 (18%)             | 37 (14%)           | 0.437 |
| Smoking | 33 (50%)             | 115 (44%)          | 0.430 |
| Vital signs and symptoms on admission | Body temperature, °C | 37.7 ± 0.9 | 37.1 ± 0.7 | <0.001 |
| | Respiration rate, breaths/min | 25.2 ± 5.1 | 20.2 ± 1.6 | <0.001 |
| | Systolic blood pressure (mmHg) | 113.5 ± 19.5 | 126.4 ± 16.5 | <0.001 |
| | Glucose (mg/dL) | 157.8 ± 72.2 | 131.6 ± 60.2 | 0.003 |
| | Potassium (mmol/L) | 4.5 ± 0.7 | 4.0 ± 0.5 | <0.001 |
| | Sodium (mmol/L) | 135.1 ± 4.7 | 137.6 ± 4.4 | <0.001 |
| | C-reactive protein (mg/L) | 157.8 ± 72.2 | 131.6 ± 60.2 | 0.003 |
| | Procalcitin (ng/mL) | 560 (131–1015) | 92 (4–20) | <0.001 |
| | hs-troponin I (pg/ml) | 49 (14–389) | 7 (4–20) | <0.001 |
| | D-dimer (ng/mL) | 560 (131–1015) | 92 (4–155) | <0.001 |
| Complications and clinical outcome | SIRS score | 2.1 ± 1.1 | 0.8 ± 0.7 | <0.001 |
| | Hospital length of stay, days | 10 (7–14) | 11 (7–15) | 0.556 |
| | Hospitalization rate of ICU, n(%) | 56 (85%) | 41 (15%) | <0.001 |
| | Discharged, n(%) | - | 197 (76%) | <0.001 |
| | Mechanical ventilation, n(%) | 56 (85%) | 5 (22%) | <0.001 |
| | Oxygen requirements, n(%) | 10 (15%) | 213 (82%) | <0.001 |

Abbreviations: hs-TnI, high-sensitive troponin I; SIRS, Systemic Inflammatory Response Syndrome; ICU, intensive care unit.
age was higher than the non-survivor group. Forty of 66 patients the non-survivor group were male (60%), while 147 of 258 patients the survivor group were male (57%). While the average age of patients the non-survivor group was 67.9 ± 13.3, the average age of patients the survivor group was 60.4 ± 14.9 and there was a statistically significant difference \( p < 0.001 \). Body temperature and respiration rates were significantly higher in the non-survivor group \( p < 0.001 \). Systolic blood pressure was lower in the non-survivor group \( p < 0.001 \). SIRS score differed significantly between the non-survivor and survivor groups \( p < 0.001 \).

When laboratory tests were compared in both groups, WBC, creatinine, sodium, potassium, glucose, CRP, procalcitonin, hs-TnI and d-dimer values were found to be statistically significantly higher in the non-survivor group, respectively, while hgb levels were found to be statistically significantly lower. While the length of hospital stay was similar in both groups, ICU hospitalization rates were significantly higher in the non-survivor group \( (56 (85%) / 41 (15%), \ p < 0.001) \) (Table 1).

The electrocardiographic features of patients were compared in non-survivor and survivor groups. Heart rate, RV strain pattern, RRBB, ST depression, T wave inversion, ST elevation, S1Q3T3, CLOCKROT and ST elevation in V1 were statistically significantly higher in the non-survivor group than in the survivor group \( p < 0.05 \) (Table 2).

The patients were then grouped according to the presence of RV strain on the ECG. In 95 of 324 COVID-19 patients included in the study, RV strain was detected by electrocardiography and its clinical and demographic characteristics are shown in Table 3. Hs-TnI and d-dimer levels were found statistically significantly higher in the group with RV strain. Hospital stay was similar in both groups, while ICU hospitalization rates were significantly higher in the non-survivor group \( (39 (41%) / 58 (25%), \ p = 0.005) \). On the contrary, the discharge rates were higher in the group without RV strain \( (46 (48%) / 151 (65%), \ p = 0.003) \) (Table 3).

Cox regression analysis was evaluated by univariate and multivariable analyzes that predicted mortality development. Age, d-dimer, hs-TnI and RV strain values were found to be statistically by multivariable analysis significant independent predictors in terms of predicting mortality \( \text{Age HR: 1.044, p = 0.001; d-dimer HR: 1.002, p = 0.026; hs-TnI HR: 1.002, p = 0.041; RV strain HR: 4.385, p < 0.001} \) (Table 4).

Death occurred in 36 (38%) patients with RV strain and 30 (13%) patients without RV strain with electrocardiography. Survival rates were assessed by Kaplan-Meier curves and there was statistically significant difference (log-rank \( p < 0.001; \text{Fig. 1} \)).

The interobserver concordance rate for RV strain was 97%. In case of disagreement, the final diagnosis was achieved by mutual agreement. The intraobserver concordance rate was 98%.

## 4. Discussion

In the present study, prognostic significance of RV strain pattern on admission ECG were investigated in patients with COVID-19. The main findings of our study are as follows:

(i) RV strain, tachycardia and S1Q3T3 in ECG were observed more frequently in non-survivor than survivors patients.

(ii) Hs-TnI and d-dimer levels were higher and mortality rates were more frequently detected in patients with RV strain.

(iii) After a multivariable survival analysis, presence of right ventricular strain on ECG, hs-TnI, d-dimer and age were independent predictors of mortality.
asymptomatically, which can lead to multiple organ failure and may result in death. Although it mainly affects the respiratory tract, other systems, including the cardiovascular system, are also affected by this infection. In addition to acute respiratory distress syndrome (ARDS) and type 1 respiratory failure, acute cardiac injury and heart failure are the most common complications [3,5,6]. It has been reported that SARS-CoV-2 infection can cause RV overload due to both lung and systemic inflammation, and can be directly linked to cardiomyocytes, causing cardiac injury [6,19]. Recently studies showed that cardiac involvement is associated with poor prognosis in these patients [20]. Patients with COVID-19 are expected to see some changes in electrocardiography, although its sensitivity and specificity values are not high [24]. In electrocardiography, right atrial strain, right ventricular dilation and hypertrophy are findings that can be observed. In pulmonary thromboembolism, sinus tachycardia, RBBB, S1Q3T3 pattern, and T wave inversion in anterior leads occur due to pressure and volume loading in the lung. Our study showed that sinus tachycardia in 99 patients (30%), complete or incomplete RBBB in 61 patients (19%), S1Q3T3 in 50 patients (15%), T wave inversion in anterior leads in 42 patients (13%).

In a recently published case series, right ventricular dilatation was described in five COVID-19 patients with critical disease [25]. In another case report with 2 COVID-19 cases, different ECG findings were observed within days [26]. In another study involving COVID-19 patients, 20% of cases had ST segment elevation / ST-T changes [27]. Previously studies demonstrated that right ventricular strain pattern is related to the pulmonary embolism and to right ventricular pressure overload with potential prognostic implications [10-12]. Our study showed that the presence of at least one classic ECG sign of right ventricular strain (29% of all patients) is associated with increased risk of death (HR: 4.4) during hospitalization. In a recent COVID-19 study RV strain values by speckle-tracking echocardiography (STE) were shown as an independent marker of mortality [8]. Due to the difficulties, accessibility and risk of infection of STE, it is important to detect RV dysfunction with ECG.

The exact cause of RV dilation and loading in patients diagnosed with COVID-19 is unknown. Right ventricular dilatation may be due to inhibition of blood flow in the lungs due to lung embolism or lung tissue damage. The direct damage of the virus to the heart tissue can be a contributing factor. COVID-19 may directly affect the myocardium through ACE-2 receptors, which are found extensively in heart tissue [5,6]. Patients infected with COVID-19 appear to be at high risk for venous thromboembolism (VTE). Abnormal coagulation parameters were detected in patients hospitalized with severe COVID-19 infection [28]. Prolonged immobilization in critically ill patients also poses a high risk for VTE. Autopsy data shows that not only in the lungs, but also in the heart, liver, kidneys and large vessels, arterial and microvascular thrombus can occur [29]. In another study comparing survivors and non-survivors with COVID-19, it was shown that non-survivors had higher levels of d-dimer and fibrin degradation products and 71.4% of them met disseminated intravascular coagulation (DIC) criteria [28]. In our study, patients with RV strain on ECG had high troponin and d-dimer levels. In addition, in our study, age, d-dimer and hs-TnI, which had prognostic significance in multivariable analysis and other studies, were determined as independent predictors of mortality.

Our study is single-center and covers only the patients who are hospitalized and treated in the hospital. Therefore, the results of the study are not valid for all COVID-19 patients. Another limitation of our study is that patients do not have old ECGs and that echocardiography was not performed simultaneously. Admission ECGs of patients have been taken and RV strain may also be developed in the follow-up of patients. The main limitation in using RV strain pattern as a prognostic tool is the fact that it occurs in about 10% of the normal population, especially due to complete and incomplete RBBB [24].
5. Conclusions

The present study of patients with COVID-19 revealed that right ventricular strain pattern at ECG on admission is associated with hospital mortality. The presence of RV strain findings detected in ECG, which is routinely examined before treatment in patients with COVID-19, may be an indicator of severe lung involvement and pulmonary embolism in COVID-19 patients. RV strain pattern detected on ECG is a prognostic marker and can be used as an indicator of prognosis in these patients. Patients with RV strain patterns, such as complete or incomplete right bundle branch block, can be identified by automated ECG interpretation, to aid the primary treating physician who is almost assuredly not an expert in ECG interpretation. It is important to recognize patients at higher risk of COVID-19 patients for poor results. Studies showing the development of RV strain pattern during hospitalization are needed for patients with normal initial ECG. Comprehensive evaluation can be made by using RV strain parameters in ECG for risk classification. Unlike age and some blood test results (D-dimer, hs-TnI), it can be helpful in determining the prognosis in that it can be checked intuitively.

Funding

None.

Declaration of Competing Interest

The authors report no relationships that could be construed as a conflict of interest.

References

[1] Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention. JAMA. 2020;323(13):1239–42.
[2] Andersen KG, Rambaut A, Lipkin WI, Holmes EC, Garry RF. The proximal origin of SARS-CoV-2. Nat Med. 2020;26(4):450–2.
[3] 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(10229):1094–106.
[4] 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(10223):497–506.
[5] Xiong T-Y, Redwood S, Prendergast B, Chen M. Coronaviruses and the cardiovascular system: acute and long-term implications. Eur Heart J. 2020;41(19):1798–800.
[6] Li B, Yang J, Zhao F, Zhi L, Wang X, Liu L, et al. Prevalence and impact of cardiovascular metabolic diseases on COVID-19 in China. Clin Res Cardiol. 2020;1–8.
[7] Wang D, Hu B, Hu C, Zhu F, Liu X, Zhang J, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus–infected pneumonia in Wuhan, China. Jama. 2020;323(11):1061–9.
[8] 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(11):2287–99.
[9] Gandhi RT, Lynch JB, Del Rio C. Mild or moderate Covid-19. N Engl J Med. 2020;383(18):1757–66.
[10] Iles S, Le Heron CJ, Davies G, Turner JG, Beckert LE. ECG score predicts those with the greatest percentage of perfusion defects due to acute pulmonary thromboembolic disease. Chest. 2004;125(5):1651–6.
[11] Kucher N, Walpoth N, Westmann K, Novouanu M, Gertsch M. QR in V1—an ECG sign associated with right ventricular strain and adverse clinical outcome in pulmonary embolism. Eur Heart J. 2003;24(12):1113–9.
[12] Punukolli G, Gowda RM, Vasavada BC, Khan IA. Role of electrocardiography in identifying right ventricular dysfunction in acute pulmonary embolism. Am J Cardiol. 2005;96(3):450–2.
[13] Vanni S, Poidori G, Vergara R, Pepe G, Nazerian P, Moroni F, et al. Prognostic value of ECG among patients with acute pulmonary embolism and normal blood pressure. Am J Med. 2009;122(3):257–64.
[14] Shopp JD, Stewart LR, Ennert TW, Kline JA. Findings from 12-lead electrocardiography that predict circulatory shock from pulmonary embolism: systematic review and meta-analysis. Acad Emerg Med. 2015;22(10):1127–37.
[15] Daniel RR, Courtney DM, Kline JA. Assessment of cardiac stress from massive pulmonary embolism with 12-lead ECG. Chest. 2001;120(2):474–81.
[16] Kulka P, McIntyre WF, Fijorek K, Mirek-Byniarska E, Byniarski L, Krupa E, et al. Electrocardiographic abnormalities in patients with acute pulmonary embolism complicated by cardiogenic shock. Am J Emerg Med. 2014;32(6):507–10.
[17] Thysgesen K, Alpert JS, Jaffe AS, Chaitman BR, Bax JJ, Morrow DA, et al. Fourth universal definition of myocardial infarction (2018). Eur Heart J. 2019;40(3):237–69.
[18] Bone RC, Balk RA, Cerra FB, Dellinger RP, Fein AM, Knaus WA, et al. Definitions for sepsis and organ failure and guidelines for the use of innovative therapies in sepsis. Chest. 1992;101(6):1644–55.
[19] Chen T, Wu D, Chen H, Yan W, Yang D, Chen G, et al. Clinical characteristics of 113 deceased patients with coronavirus disease 2019: retrospective study. Bmj. 2020; 368:
[20] Santoso A, Pranata R, Winobro A, Al-Farabi MJ, Huang I, Antariksa B. Cardiac injury is associated with mortality and critically ill pneumonia in COVID-19: a meta-analysis. Am J Emerg Med. 2020;30735-6757(20).
[21] Xie M, Li Y, Cheng TO, Wang X, Dong N, Nie X, et al. The effect of right ventricular myocardial remodeling on ventricular function as assessed by two-dimensional speckle tracking echocardiography in patients with tetralogy of Fallot: a single center experience from China. Int J Cardiol. 2015;178:300–7.
[22] Park SJ, Park J-H, Lee HS, Kim MS, Park YK, Park Y, et al. Impaired RV global longitudinal strain is associated with poor long-term clinical outcomes in patients with acute inferior STEMI. JACC Cardiovasc Imaging. 2015;8(2):1625–37.
[23] Houard L, Benaets M-B. de Ravenstein CdM, Rousseau MF, Ahn SA, Amzulescu M-S, et al. The right ventricle in COVID-19: a single center autopsy experience from New Orleans. Lancet. 2020;386(10003):1237–83.
[24] Richman PB, Lourfi H, Lester SJ, Campbell P, Matthews J, Friese J, et al. Electrocardiographic findings in emergency department patients with pulmonary embolism. J Emerg Med. 2004;27(2):121–6.
[25] Creeze-Bulos C, Hockstein M, Amin N, Melhem S, Truong A, Sharifpour M. Acute Coronary Syndrome Associated with Right Ventricular Injury: A Systematic Review and Meta-Analysis. Acad Emerg Med. 2020;22(10):1127–37.
[26] He J, Wu B, Chen Y, Tang J, Liu Q, Zhou S, et al. Characteristic ECG manifestations in patients with COVID-19. Can J Cardiol. 2020;36(6).
[27] Deng Q, Hu B, Zhang Y, Wang H, Zhou X, Hu W, et al. Suspected myocardial injury in patients with COVID-19: evidence from front-line clinical observation in Wuhan, China. Int J Cardiol. 2020;311:116–21.
[28] Tang N, Li D, Wang X, Sun Z. Abnormal coagulation parameters are associated with poor prognosis in patients with novel coronavirus pneumonia. J Thromb Haemost. 2020;18(5):1233–4.
[29] Fox SE, Akmatbekov A, Harbert JL, Li G, Brown JO, Vander Heide RS, et al. Pulmonary and cardiac pathology in Covid-19: the first autopsy series from New Orleans. Lancet Respir Med. 2020;8(7):681–6.