Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Review Article

Electrocardiographic features of patients with COVID-19: One year of unexpected manifestations

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1. Introduction

Coronavirus Disease 2019 (COVID-19) is the clinical manifestation of infection with Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) [1 -3]. COVID-19 is frequently characterized by symptoms and signs of respiratory tract infection which may progress to pneumonia, acute respiratory distress syndrome (ARDS) and shock. [1, 2, 4] Thus, much of the focus has been on the respiratory system.

Nonetheless, COVID-19 can also cause a variety of cardiovascular complications including myocardial injury, myocarditis, acute myocardial infarction, stress cardiomyopathy, heart failure, dysrhythmias, and thromboembolic events [5 14]. In this context, standard electrocardiography (ECG) showed to be a crucial test in the diagnosis of cardiac complications in patients with SARS-CoV-2. A study of 756 patients hospitalized with COVID-19 in New York, documented a range of COVID-19-related ECG findings including atrial fibrillation (5.6%), atrial and ventricular premature beats (7.7% and 3.4%, respectively), right bundle branch block (7.8%), left bundle branch block (1.5%), T-wave inversion (10.5%), and nonspecific repolarization abnormalities (29.0%) [15]. These manifestations are believed to be the result of several pathogenetic mechanisms including cytokine and Angiotensin II storms, activation of coagulation cascade, hypoxic injury, endothelial and myocardial injuries, and atherosclerotic plaque destabilization and rupture [5, 7, 16, 17].

Several evidences of uncommon ECG manifestations of COVID-19 have been recently accrued. A paper from our group [18] published in the 2020 August issue of the *European Journal of Internal Medicine* [18] was one of the first studies to report a wide spectrum of unexpected ECG features of COVID-19 which exhibited a late onset and mostly occurred after recovery from the acute phase. In patients hospitalized for COVID-19 pneumonia, we found a 6% incidence of atrial fibrillation, a 2% incidence of brady-tachy syndrome, a 2% incidence of persistent ST-T changes not associated with increase in troponin I levels nor pericardial effusion, and a 12% incidence of ST-T changes associated with acute pericarditis [18].

The main aim of this narrative review was to explore incidence and pathogenesis of ECG features of COVID-19, with particularly emphasis to “unexpected” manifestations.

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Our review was performed according to standard methods. [19] We searched for eligible studies or case reports using research methodology filters [20]. We used PubMed, Scopus, and Web of Science for literature searches. The following search terms were used: "ECG", "electrocardiography", "EKG", "COVID-19″, "SARS-CoV-2″, and "coronavirus".

2. "Typical" ECG features of COVID-19 complications

At the beginning of the pandemic, much attention has been focused on ECG features of "common" cardiovascular complications of SARS-CoV-2 infections [8 11]. Several reports described "typical" features of COVID-19 complications including arrhythmias, ischemic ST-T abnormalities (spanning from acute coronary syndromes to Takotsubo syndrome), pulmonary embolism, acute heart failure, and myocarditis [8 11]. Remarkably, ECG abnormalities are common, being present up to 93% of critically ill patients [21]. For these conditions, interpretation of the ECG is unchanged from the non-COVID-19 patient [16].

2.1. Sinus tachycardia

It is the most common ECG manifestation overall in patients with COVID-19. It may reflect several underlying mechanisms including intrinsic sinus node hyperactivity, autonomic dysfunction and a hyperadrenergic state (fever, hypovolemia, hypoxia, pain, anxiety, and hypoperfusion) [22]. Nonetheless, inflammatory cytokines released by patients with COVID-19 may affect the function of myocardial ion channels and perpetuate the sinus tachycardia [23]. As in the general population, other etiologies of sinus tachycardia should be considered (i.e. pulmonary embolism) [24].

2.2. Atrial arrhythmias

Atrial arrhythmias are the most commonly reported features in patients with COVID-19. Specifically, atrial fibrillation is commonly observed among COVID-19 patients (as detected in 19% to 21% of all cases) [25, 26].

The etiology of atrial arrhythmias remains to be fully elucidated. However, a reduction in angiotensin-converting enzyme 2 (ACE2) receptor availability, CD147- and sialic acid-spike protein interaction, enhanced inflammatory signaling, direct viral endothelial damage, metabolic derangements, electrolytes and acid-base balance abnormalities in the acute phase of COVID-19 have been suggested as putative mechanisms [27].

For atrial fibrillation, it is worth mentioning that epicardial fat has been linked to atrial electrical remodeling and the progression of atrial fibrillation [28, 29]. Although it is likely that atrial fibrillation may be related to COVID-19 infection (systemic hyperinflammation, fever, hypoxia, adrenergic tone), the involvement of epicardial adipocytes (as demonstrated by ECG signs of pericarditis and development of pericardial effusion) during SARS-CoV-2 infection could predispose to the development of atrial fibrillation [18].

2.3. Ventricular arrhythmias

These arrhythmias may occur among COVID-19 patients with myocarditis, metabolic abnormalities, or treated with QT interval prolonging medications [5, 16, 30].

Abrams and co-workers reviewed demographics, laboratory and cardiac tests, medications, and cardiac rhythm proximate to death or initiation of comfort care for patients hospitalized with a positive SARS-CoV-2 reverse-transcriptase polymerase chain reaction in three New York City hospitals between March 1 and April 3, 2020. They documented that the last cardiac rhythm recorded was ventricular tachycardia or fibrillation in 5.3% of all cases [31].

Furthermore, life threatening ventricular arrhythmias are reported to be more common in patients with elevated serum levels of cardiac troponins [30, 32].

2.4. Myocardial ischemia and injury

A plethora of ischemic and myocardial injuries manifestations have been documented among hospitalized patients with COVID-19 [5, 32 34].

In a retrospective observational study including patients with COVID-19 admitted at the Wuhan Asia General hospital, ST-T abnormalities (40%) were the most common ECG feature [35].

Of note, myocardial injury during the acute phase of COVID-19 demonstrates ST segment deviations (both elevation or depression), pathological Q waves, and T wave inversion at standard ECG [21, 36 38]. Although the distinction between a ST-elevation myocardial infarction and myocarditis remains difficult, diagnosis of acute myocardial infarction is suggested with focal ST-segment elevations; conversely, myocardial injury demonstrates diffuse or widespread ST-segment elevation [39].

It has been proposed that mechanisms of SARS-CoV-2 myocardial injury may be explained by a combination of direct cell injury and T-lymphocyte-mediated cytoxicity [40, 41].

2.5. Pulmonary embolism

A high prevalence of venous thromboembolism (VTE) is reported during hospitalization for COVID-19 [42]. The most common ECG finding in the setting of a pulmonary embolism is sinus tachycardia [43]. This associated ECG condition is also confirmed among COVID-19 patients [16, 44]. The $S_1Q_3T_3$ sign (prominent S wave in lead I, Q wave and inverted T wave in lead III) is a classic sign of acute cor pulmonale (acute pressure and volume overload of the right ventricle because of pulmonary hypertension) with increased right ventricular strain [45].

Nonetheless, a single center, retrospective observational cohort study of COVID-19 patients diagnosed with pulmonary embolism showed that the $S_1Q_3T_3$ sign was present in less than 10% of cases and that non-specific ST-T abnormalities or T wave changes were the most common ECG findings of pulmonary embolism [44].

3. "Unexpected" ECG features of COVID-19

Evidences on unexpected ECG features of COVID-19 have been recently accrued, showing that uncertainties still overshadow our clinical knowledge in the field [16, 36].

Interestingly, in our previous report of ECG features of patients with COVID-19 pneumonia, we documented that the development of ECG abnormalities during hospitalization was unrelated to the severity of respiratory function [18]. Moreover, abnormal serum levels of high sensitivity troponin I were recorded in the 38% of cases and ECG abnormalities showed a late onset from hospitalization and initiation of COVID-19 symptoms. The average time for development of ECG abnormalities was 20 and 30 days from admission and onset of symptoms, respectively [18]. Notably, a large proportion of patients (54%) experienced ECG abnormalities immediately before the scheduled discharge from hospital and after 2 consecutive negative nasopharyngeal swabs [18].

3.1. Right ventricular strain

COVID-19 patients with acute respiratory failure may present QRS complex axis deviation with right ventricular strain (prominent R waves in leads V_1 and V_2, ST segment depression or T wave inversion in leads II, III, aVF, V_1,V_2, V_3, and V_4) [33]. Of note, right ventricular strain seems to be associated with an increased risk of death or need of mechanical ventilation during hospitalization [33, 46].

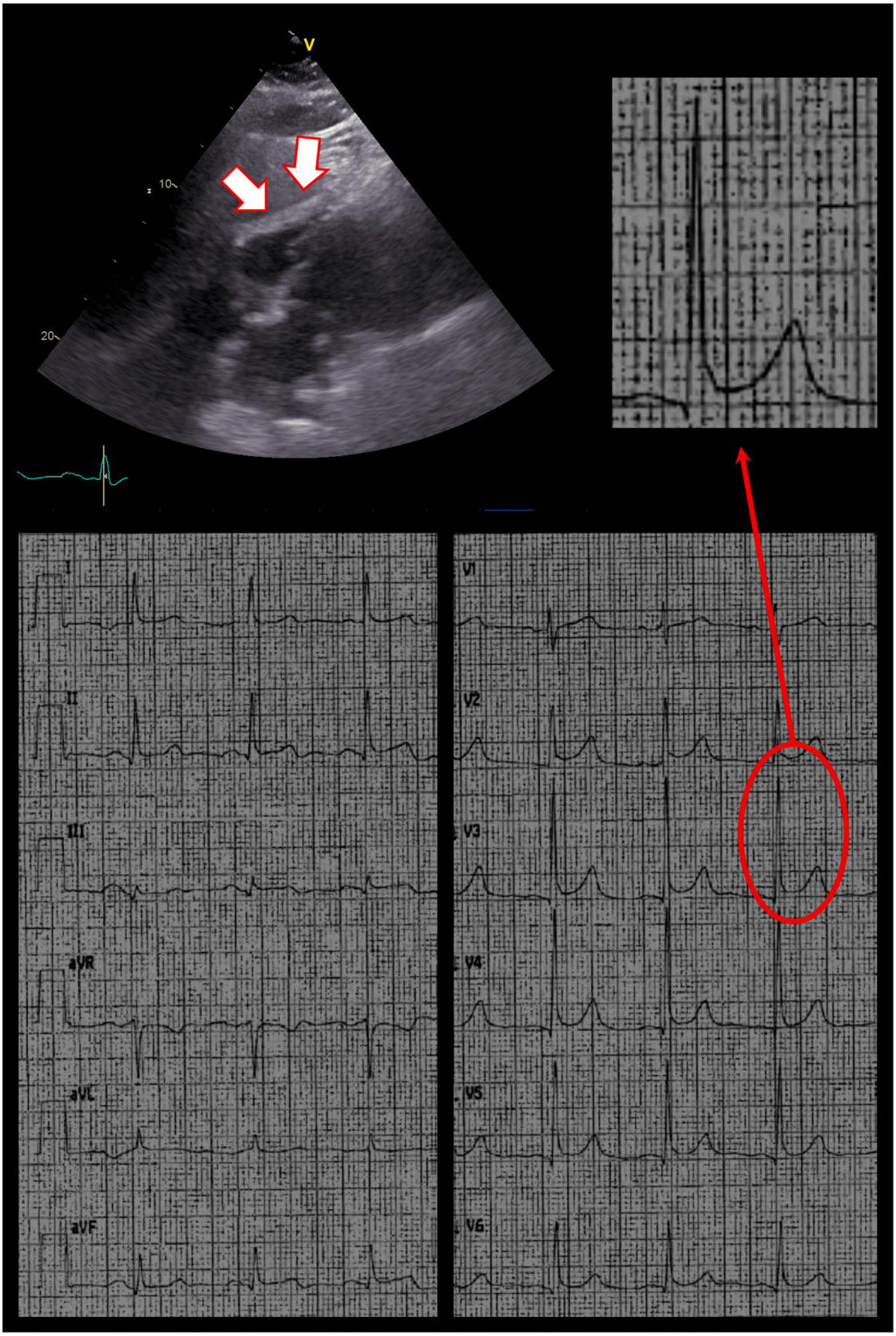

Fig. 1. A 79-year-old white woman who developed during hospitalization COVID-19 pneumonia, chest pain with ECG signs of acute pericarditis and significant pericardial effusion [18]. After 1 month after discharge from hospital, the patient was asymptomatic and the echocardiographic examination documented complete regression of pericardial effusion (upper panel). However, standard ECG revealed the persistence of signs of pericarditis (lower panel).

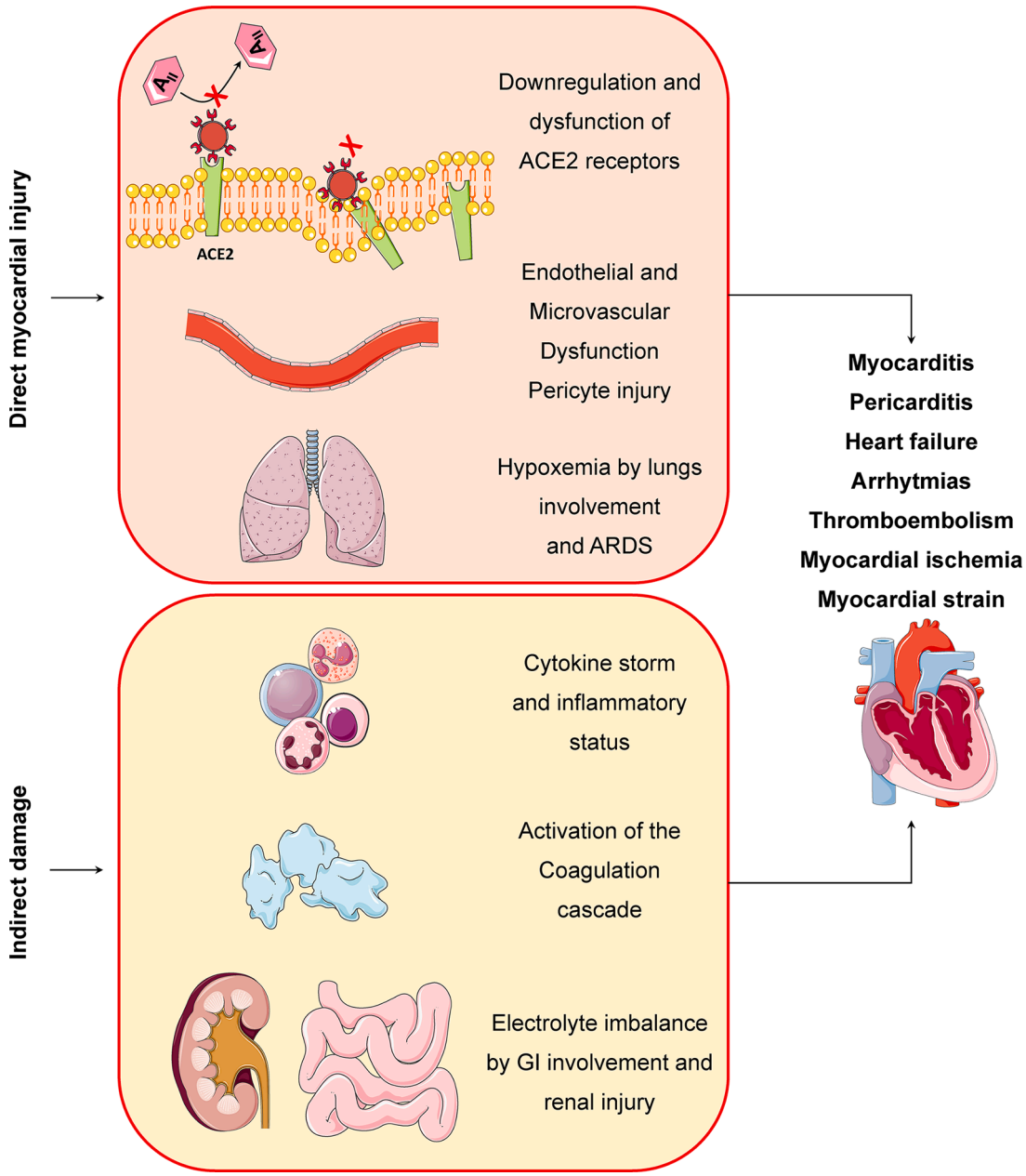

Fig. 2. Main mechanisms of cardiac involvement during SARS-CoV-2 infection (including direct injury and indirect damage). See text for details. **Legend:** A_{II} = angiotensin II; ACE2 = angiotensin converting enzyme 2 receptor; ARDS = Acute respiratory distress syndrome; GI = gastrointestinal.

3.2. *Brady-arrhythmias and atrioventricular blocks*

Incidence of bradicardias, atrioventricular blocks, and brady-tachy syndromes is not well characterized among COVID-19 patients [16, 18, 47].

To date, these ECG manifestations are considered as disease-caused deterioration [47].

However, a recent case series by Dagher and co-workers [48] described four cases of COVID-19 patients who developed a transient high-degree atrioventricular block during the course of their hospitalization, not requiring permanent pacing [48]. Similar findings were also reported in our cohort [18] and by Eneizat Mahdawi and co-workers in a case series of heart blocks [49].

3.3. *ECG features of pericardial disease*

Postmortem studies have identified pericarditis in about 20% of the COVID-19 cases [50, 51] and several case reports reported acute pericarditis in patients with SARS-CoV-2 infection with typical ECG signs (diffuse ST elevation and PR depression) [52 56].

Data from 63,822 COVID patients attending 50 Spanish emergency department during the COVID outbreak were used to analyze the frequency of (myo)pericarditis [57]. Compared with general emergency department population, COVID patients developed more frequently (myo)pericarditis (odds ratio [OR]: 1.45, 95% confidence interval [CI]: 1.07–1.97) [57]. Similarly, in a retrospective cohort study involving 718,365 patients with COVID-19, 10,706 (1.5%) patients developed new-onset pericarditis with a 6-months all-cause mortality of 15.5% (vs 6.7% in matched controls, OR: 2.55, 95% CI: 2.24 2.91) [40].

In our study cohort [18], ECG signs of acute pericarditis were the most common ECG manifestations of COVID-19. Notably, we diagnosed acute pericarditis by ECG evidence of new widespread concave ST elevation and PR depression throughout most of the limb (I, II, III, aVL, aVF) and precordial (V_2-V_6) leads, reciprocal ST depression, and PR

elevation in aVR, and a ST segment/T wave ratio> 0.25 [58]. We also noted late persistence of ECG signs of acute pericarditis (Fig. 1). Similar findings were documented by Soewono [59] and Eiros and co-workers [60]. Specifically, Soewono et al. described the case of a 30-year-old man with diagnosis of acute pericarditis 6 weeks after respiratory symptoms and a positive test for SARS-CoV-2 infection [59]. Eiros et al. studied 139 health-care workers with confirmed past SARS-CoV-2 infection. Participants underwent clinical assessment, electrocardiography, laboratory tests including immune cell profiling and cardiac magnetic resonance (CMR). Overall, 14% of the total participants fulfilled the pericarditis criteria at week 10 [60].

To date, the exact pathophysiological mechanism of pericardial involvement is not fully understood. As proposed mechanisms, systemic inflammatory reaction (with cytokine storm), and endothelial damage induced by COVID-19 may lead to pericardial involvement [52]. Furthermore, COVID-19 induced pericarditis might reflect the expression of ACE2 receptors in epicardial adipocites (mediating the cell entry of SARS-CoV-2) [17, 61 65], and possibly triggering local inflammation [63, 65 70].

3.4. Brugada-like pattern

Two case reports documented Brugada patterns in patients with COVID-19 [71, 72]. In the first report [71], standard ECG revealed a Brugada-like pattern in a 61-year-old man presented with fever, shortness of breath, and chest pain (with coronary angiography demonstrating normal coronary arteries).

In the second, a 49-year-old Bangladeshi man without significant medical history and positive for COVID-19 showed a Brugada syndrome, with the combination of the Brugada ECG pattern and clinical symptoms [72].

4. Conclusions

COVID-19 impacts the cardiovascular system, causing a variety of cardiac complications and leading to a range of ECG abnormalities [73, 74] (Fig. 2). Cardiac injury is found in 7%−17% of COVID-19 patients, and it is associated with a higher risk of mortality [12 14]. Therefore, clinicians must be aware of the ECG manifestations of COVID-19.

As the body of academic literature is expanding, it is also mandatory to understand uncommon ECG manifestations of COVID-19. Some patients with pericarditis may not have chest pain even with myocarditis coexists. On the other hand, several patients with acute pericarditis develop significant pericardial effusion necessitating pericardial drainage [53, 55, 75].

It's now well established that several uncommon ECG manifestations of SARS-CoV-2 infection are associated with an increased risk of adverse outcome [16, 36, 76]. These conditions require an early diagnosis, a proper workup and specific management strategies based on organ involvement.

Declaration of Competing Interest

None of the authors of this study has financial or other reasons that could lead to a conflict of interest.

References

[1] Cheng ZJ, Shan J. 2019 Novel coronavirus: where we are and what we know. Infection 2020;48:155–63. https://doi.org/10.1007/s15010-020-01401-y.

[2] Yang W, Cao Q, Qin L, Wang X, Cheng Z, Pan A, Dai J, Sun Q, Zhao F, Qu J, et al. Clinical characteristics and imaging manifestations of the 2019 novel coronavirus disease (COVID-19):A multi-center study in Wenzhou city, Zhejiang, China. J Infect 2020;80:388–93. 10.1016/j.jinf.2020.02.016.

[3] Angeli F, Zappa M, Reboldi G, Trapasso M, Cavallini C, Spanevello A, Verdecchia P. The pivotal link between ACE2 deficiency and SARS-CoV-2 infection: one year later. Eur J Intern Med 2021. https://doi.org/10.1016/j.ejim.2021.09.007.

[4] Brussow H. The Novel Coronavirus - A Snapshot of Current Knowledge. Microb Biotechnol 2020;13:607–12. https://doi.org/10.1111/1751-7915.13557.

[5] Long B, Brady WJ, Koyfman A, Gottlieb M. Cardiovascular complications in COVID-19. Am J Emerg Med 2020;38:1504–7. https://doi.org/10.1016/j.ajem.2020.04.048.

[6] Jr Sandoval Y, Januzzi JL, Jaffe AS. Cardiac Troponin for Assessment of Myocardial Injury in COVID-19: JACC Review Topic of the Week. J Am Coll Cardiol 2020;76:1244–58. 10.1016/j.jacc.2020.06.068.

[7] Angeli F, Marazzato J, Verdecchia P, Balestrino A, Bruschi C, Ceriana P, Chiovato L, Dalla Vecchia LA, De Ponti R, Fanfulla F, et al. Joint effect of heart failure and coronary artery disease on the risk of death during hospitalization for COVID-19. Eur J Intern Med 2021;89:81–6. 10.1016/j.ejim.2021.04.007.

[8] Zheng YY, Ma YT, Zhang JY, Xie X. COVID-19 and the cardiovascular system. Nat Rev Cardiol 2020;17:259–60. https://doi.org/10.1038/s41569-020-0360-5.

[9] Akhmerov A, Marban E. COVID-19 and the Heart. Circ Res 2020. https://doi.org/10.1161/CIRCRESAHA.120.317055.

[10] Clerkin KJ, Fried JA, Raikhelkar J, Sayer G, Griffin JM, Masoumi A, Jain SS, Burkhoff D, Kumaraiah D, Rabbani L, et al. Coronavirus Disease 2019 (COVID-19) and Cardiovascular Disease. Circulation 2020. https://doi.org/10.1161/CIRCULATIONAHA.120.046941.

[11] Fried JA, Ramasubbu K, Bhatt R, Topkara VK, Clerkin KJ, Horn E, Rabbani L, Brodie D, Jain SS, Kirtane A, et al. The Variety of Cardiovascular Presentations of COVID-19. Circulation 2020. https://doi.org/10.1161/CIRCULATIONAHA.120.047164.

[12] Shi S, Qin M, Shen B, Cai Y, Liu T, Yang F, Gong W, Liu X, Liang J, Zhao Q, 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.

[13] Wang D, Hu B, Hu C, Zhu F, Liu X, Zhang J, Wang B, Xiang H, Cheng Z, Xiong Y, et al. Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China. JAMA 2020;323:1061–9. https://doi.org/10.1001/jama.2020.1585.

[14] Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, Xiang J, Wang Y, Song B, Gu X, 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. https://doi.org/10.1016/S0140-6736(20)30566-3.

[15] McCullough SA, Goyal P, Krishnan U, Choi JJ, Safford MM, Okin PM. Electrocardiographic Findings in Coronavirus Disease-19: Insights on Mortality and Underlying Myocardial Processes. J Card Fail, 2020;26:626–32. https://doi.org/10.1016/j.cardfail.2020.06.005.

[16] Long B, Brady WJ, Bridwell RE, Ramzy M, Montrief T, Singh M, Gottlieb M. Electrocardiographic manifestations of COVID-19. Am J Emerg Med 2021;41:96–103. https://doi.org/10.1016/j.ajem.2020.12.060.

[17] Verdecchia P, Cavallini C, Spanevello A, Angeli F. The pivotal link between ACE2 deficiency and SARS-CoV-2 infection. Eur J Intern Med 2020;76:14–20. https://doi.org/10.1016/j.ejim.2020.04.037.

[18] Angeli F, Spanevello A, De Ponti R, Visca D, Marazzato J, Palmiotto G, Feci D, Reboldi G, Fabbri LM, Verdecchia P. Electrocardiographic features of patients with COVID-19 pneumonia. Eur J Intern Med 2020;78:101–6. 10.1016/j.ejim.2020.06.015.

[19] Haynes RB, Kastner M, Wilczynski NL, Hedges T. Developing optimal search strategies for detecting clinically sound and relevant causation studies in EMBASE. BMC Med Inform Decis Mak 2005;5:8. https://doi.org/10.1186/1472-6947-5-8.

[20] Wong SS, Wilczynski NL, Haynes RB, Hedges T. Developing optimal search strategies for detecting clinically relevant qualitative studies in MEDLINE. Stud Health Technol Inform 2004;107:311–6.

[21] Bertini M, Ferrari R, Guardigli G, Malagu M, Vitali F, Zucchetti O, D'Aniello E, Volta CA, Cimaglia P, Piovaccari G, et al. Electrocardiographic features of 431 consecutive, critically ill COVID-19 patients: an insight into the mechanisms of cardiac involvement. Europace 2020;22:1848–54. https://doi.org/10.1093/europace/euaa258.

[22] Olshansky B, Sullivan RM. Inappropriate sinus tachycardia. Europace 2019;21:194–207. https://doi.org/10.1093/europace/euy128.

[23] Lazzerini PE, Laghi-Pasini F, Boutjdir M, Capecchi PL. Cardioimmunology of arrhythmias: the role of autoimmune and inflammatory cardiac channelopathies. Nat Rev Immunol 2019;19:63–4. https://doi.org/10.1038/s41577-018-0098-z.

[24] Desai AD, Boursiquot BC, Melki L, Wan EY. Management of Arrhythmias Associated with COVID-19. Curr Cardiol Rep 2020;23:2. https://doi.org/10.1007/s11886-020-01434-7.

[25] Gopinathannair R, Merchant FM, Lakkireddy DR, Etheridge SP, Feigofsky S, Han JK, Kabra R, Natale A, Poe S, Saha SA, et al. COVID-19 and cardiac arrhythmias: a global perspective on arrhythmia characteristics and management strategies. J Interv Card Electrophysiol 2020;59:329–36. https://doi.org/10.1007/s10840-020-00789-9.

[26] Inciardi RM, Adamo M, Lupi L, Cani DS, Di Pasquale M, Tomasoni D, Italia L, Zaccone G, Tedino C, Fabbricatore D, et al. Characteristics and outcomes of patients hospitalized for COVID-19 and cardiac disease in Northern Italy. Eur Heart J 2020;41:1821–9. https://doi.org/10.1093/eurheartj/ehaa388.

[27] Gawalko M, Kaplon-Cieslicka A, Hohl M, Dobrev D, Linz D. COVID-19 associated atrial fibrillation: Incidence, putative mechanisms and potential clinical implications. Int J Cardiol Heart Vasc 2020;30:100631. https://doi.org/10.1016/j.ijcha.2020.100631.

[28] Friedman DJ, Wang N, Meigs JB, Hoffmann U, Massaro JM, Fox CS, Magnani JW. Pericardial fat is associated with atrial conduction: the Framingham Heart Study. J Am Heart Assoc 2014;3:e000477. https://doi.org/10.1161/JAHA.113.000477.

[29] Thanassoulis G, Massaro JM, O'Donnell CJ, Hoffmann U, Levy D, Ellinor PT, Wang TJ, Schnabel RB, Vasan RS, Fox CS, et al. Pericardial fat is associated with prevalent atrial fibrillation: the Framingham Heart Study. Circ Arrhythm Electrophysiol 2010;3:345–50. https://doi.org/10.1161/CIRCEP.109.912055.
[30] Kang Y, Chen T, Mui D, Ferrari V, Jagasia D, Scherrer-Crosbie M, Chen Y, Han Y. Cardiovascular manifestations and treatment considerations in COVID-19. Heart 2020;106:1132–41. https://doi.org/10.1136/heartjnl-2020-317056.
[31] Abrams MP, Wan EY, Waase MP, Morrow JP, Dizon JM, Yarmohammadi H, Berman JP, Rubin GA, Kushnir A, Poterucha TJ, et al. Clinical and cardiac characteristics of COVID-19 mortalities in a diverse New York City Cohort. J Cardiovasc Electrophysiol 2020;31:3086–96. https://doi.org/10.1111/jce.14772.
[32] Guo T, Fan Y, Chen M, Wu X, Zhang L, He T, Wang H, Wan J, Wang X, Lu Z. 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.
[33] Elias P, Poterucha TJ, Jain SS, Sayer G, Raikhelkar J, Fried J, Clerkin K, Griffin J, DeFilippis EM, Gupta A, et al. The Prognostic Value of Electrocardiogram at Presentation to Emergency Department in Patients With COVID-19. Mayo Clin Proc 2020;95:2099–109. https://doi.org/10.1016/j.mayocp.2020.07.028.
[34] Doyen D, Moceri P, Ducreux D, Dellamonica J. Myocarditis in a patient with COVID-19: a cause of raised troponin and ECG changes. Lancet 2020;395:1516. https://doi.org/10.1016/S0140-6736(20)30912-0.
[35] Li Y, Liu T, Tse G, Wu M, Jiang J, Liu M, Tao L. Electrocardiograhic characteristics in patients with coronavirus infection: A single-center observational study. Ann Noninvasive Electrocardiol 2020;25:e12805. https://doi.org/10.1111/anec.12805.
[36] Mehraeen E, Seyed Alinaghi SA, Nowroozi A, Dadras O, Alilou S, Shobeiri P, Behnezhad F, Karimi A. A systematic review of ECG findings in patients with COVID-19. Indian Heart J 2020;72:500–7. https://doi.org/10.1016/j.ihj.2020.11.007.
[37] Ajmal M, Butt K, Moukabary T. COVID-19 Disease and its Electrocardiographic Manifestations: Our Experience. Am J Med 2021;134:e477–9. https://doi.org/10.1016/j.amjmed.2021.03.030.
[38] Jr Siripanthong B, Nazarian S, Muser D, Deo R, Santangeli P, Khanji MY, Cooper LT, Chahal CAA. Recognizing COVID-19-related myocarditis: The possible pathophysiology and proposed guideline for diagnosis and management. Heart Rhythm 2020;17:1463–71. https://doi.org/10.1016/j.hrthm.2020.05.001.
[39] Bangalore S, Sharma A, Slotwiner A, Yatskar L, Harari R, Shah B, Ibrahim H, Friedman GH, Thompson C, Alviar CL, et al. ST-Segment Elevation in Patients with Covid-19 - A Case Series. N Engl J Med 2020;382:2478–80. https://doi.org/10.1056/NEJMc2009020.
[40] Buckley BJR, Harrison SL, Fazio-Eynullayeva E, Underhill P, Lane DA, Lip GYH. Prevalence and clinical outcomes of myocarditis and pericarditis in 718,365 COVID-19 patients. Eur J Clin Invest 2021:e13679. https://doi.org/10.1111/eci.13679.
[41] Tavazzi G, Pellegrini C, Maurelli M, Belliato M, Sciutti F, Bottazzi A, Sepe PA, Resasco T, Camporotondo R, Bruno R, et al. Myocardial localization of coronavirus in COVID-19 cardiogenic shock. Eur J Heart Fail 2020;22:911–5. https://doi.org/10.1002/ejhf.1828.
[42] Jevnikar M, Sanchez O, Humbert M, Parent F. Prevalence of pulmonary embolism in patients with COVID-19 at the time of hospital admission and role for pre-test probability scores and home treatment. Eur Respir J 2021;58. https://doi.org/10.1183/13993003.01033-2021.
[43] Ullman E, Brady WJ, Perron AD, Chan T, Mattu A. Electrocardiographic manifestations of pulmonary embolism. Am J Emerg Med 2001;19:514–9. https://doi.org/10.1053/ajem.2001.27172.
[44] Kho J, Ioannou A, Van den Abbeele K, Mandal AKJ, Missouris CG. Pulmonary embolism in COVID-19: Clinical characteristics and cardiac implications. Am J Emerg Med 2020;38:2142–6. https://doi.org/10.1016/j.ajem.2020.07.054.
[45] Chan TC, Vilke GM, Pollack M, Brady WJ. Electrocardiographic manifestations: pulmonary embolism. J Emerg Med 2001;21:263–70. https://doi.org/10.1016/s0736-4679(01)00389-4.
[46] Barman HA, Atici A, Sahin I, Dogan O, Okur O, Tugrul S, Avci I, Yildirmak MT, Gungor B, Dogan SM. Prognostic value of right ventricular strain pattern on ECG in COVID-19 patients. Am J Emerg Med 2021;49:1–5. https://doi.org/10.1016/j.ajem.2021.05.039.
[47] He J, Wu B, Chen Y, Tang J, Liu Q, Zhou S, Chen C, Qin Q, Huang K, Lv J, et al. Characteristic Electrocardiographic Manifestations in Patients With COVID-19. Can J Cardiol 2020;36. https://doi.org/10.1016/j.cjca.2020.03.028. 966 e1-966 e4.
[48] Dagher L, Wanna B, Mikdadi G, Young M, Sohns C, Marrouche NF. High-degree atrioventricular block in COVID-19 hospitalized patients. Europace 2021;23:451–5. https://doi.org/10.1093/europace/euaa333.
[49] Eneizat Mahdawi T, Wang H, Haddadin FI, Al-Qaysi D, Wylie JV. Heart block in patients with coronavirus disease 2019: A case series of 3 patients infected with SARS-CoV-2. HeartRhythm Case Rep 2020;6:652–6. https://doi.org/10.1016/j.hrcr.2020.06.014.
[50] Basso C, Leone O, Rizzo S, De Gaspari M, van der Wal AC, Aubry MC, Bois MC, Lin PT, Maleszewski JJ, Stone JR. Pathological features of COVID-19-associated myocardial injury: a multicentre cardiovascular pathology study. Eur Heart J 2020;41:3827–35. https://doi.org/10.1093/eurheartj/ehaa664.
[51] Hanley B, Naresh KN, Roufosse C, Nicholson AG, Weir J, Cooke GS, Thursz M, Manousou P, Corbett R, Goldin R, et al. Histopathological findings and viral tropism in UK patients with severe fatal COVID-19: a post-mortem study. Lancet Microbe 2020;1:e245–53. https://doi.org/10.1016/S2666-5247(20)30115-4.
[52] Furqan MM, Verma BR, Cremer PC, Imazio M, Klein AL. Pericardial Diseases in COVID19: a Contemporary Review. Curr Cardiol Rep 2021;23:90. https://doi.org/10.1007/s11886-021-01519-x.
[53] Asif T, Kassab K, Iskander F, Alyousef T. Acute Pericarditis and Cardiac Tamponade in a Patient with COVID-19: A Therapeutic Challenge. Eur J Case Rep Intern Med 2020;7:001701. https://doi.org/10.12890/2020_001701.
[54] Blagojevic NR, Bosnjakovic D, Vukomanovic V, Arsenovic S, Lazic JS, Tadic M. Acute pericarditis and severe acute respiratory syndrome coronavirus 2: Case report. Int J Infect Dis 2020;101:180–2. https://doi.org/10.1016/j.ijid.2020.09.1440.
[55] Fox K, Prokup JA, Butson K, Jordan K. Acute Effusive Pericarditis: A Late Complication of COVID-19. Cureus 2020;12:e9074. https://doi.org/10.7759/cureus.9074.
[56] Kumar R, Kumar J, Daly C, Edroos SA. Acute pericarditis as a primary presentation of COVID-19. BMJ Case Rep 2020;13. https://doi.org/10.1136/bcr-2020-237617.
[57] Miro O, Llorens P, Jimenez S, Pinera P, Burillo-Putze G, Martin A, Martin-Sanchez FJ, Gonzalez Del Castillo J, Spanish n. Investigators in Emergency Situations TeAm, Frequency of five unusual presentations in patients with COVID-19: results of the UMC-19-S1. Epidemiol Infect 2020;148:e189. https://doi.org/10.1017/S0950268820001910.
[58] Adler Y, Charron P, Imazio M, Badano L, Baron-Esquivias G, Bogaert J, Brucato A, Gueret P, Klingel K, Lionis C, et al. 2015 ESC Guidelines for the diagnosis and management of pericardial diseases: The Task Force for the Diagnosis and Management of Pericardial Diseases of the European Society of Cardiology (ESC) Endorsed by: The European Association for Cardio-Thoracic Surgery (EACTS). Eur Heart J 2015;36:2921–64. https://doi.org/10.1093/eurheartj/ehv318.
[59] Soewono KY, Raney 3rd KC, Sidhu MS. Pericarditis with pericardial effusion as a delayed complication of COVID-19. Proc (Bayl Univ Med Cent) 2021;34:629–30. https://doi.org/10.1080/08998280.2021.1918975.
[60] Eiros, R., Pericarditis and myocarditis long after SARS-CoV-2 infection: a cross-sectional descriptive study in health-care workers. https://www.medrxiv.org/content/10.1101/2020.07.12.20151316v1, 2020.
[61] Patel VB, Basu R, Oudit GY. ACE2/Ang 1-7 axis: A critical regulator of epicardial adipose tissue inflammation and cardiac dysfunction in obesity. Adipocyte 2016;5:306–11. https://doi.org/10.1080/21623945.2015.1131881.
[62] Verdecchia P, Cavallini C, Spanevello A, Angeli F. The pivotal link between ACE2 deficiency and SARS-CoV-2 infection. Eur J Intern Med 2020. https://doi.org/10.1016/j.ejim.2020.04.037.
[63] Verdecchia P, Reboldi G, Cavallini C, Mazzotta G, Angeli F. [ACE-inhibitors, angiotensin receptor blockers and severe acute respiratory syndrome caused by coronavirus]. G Ital Cardiol (Rome) 2020;21:321–7. https://doi.org/10.1714/3343.33127.
[64] Angeli F, Reboldi G, Verdecchia P. Ageing, ACE2 deficiency and bad outcome in COVID-19. Clin Chem Lab Med 2021;59:1607–9. https://doi.org/10.1515/cclm-2021-0658.
[65] Verdecchia P, Cavallini C, Spanevello A, Angeli F. COVID-19: ACE2centric Infective Disease? Hypertension 2020;76:294–9. https://doi.org/10.1161/HYPERTENSIONAHA.120.15353.
[66] Angeli F, Masnaghetti S, Visca D, Rossoni A, Taddeo S, Biagini F, Verdecchia P. Severity of COVID-19: The importance of being hypertensive. Monaldi Arch Chest Dis 2020;90. https://doi.org/10.4081/monaldi.2020.1372.
[67] Angeli F, Reboldi G, Verdecchia P. SARS-CoV-2 infection and ACE2 inhibition. J Hypertens 2021;39:1555–8. https://doi.org/10.1097/HJH.0000000000002859.
[68] Angeli F, Spanevello A, Reboldi G, Visca D, Verdecchia P. SARS-CoV-2 vaccines: Lights and shadows. Eur J Intern Med 2021;88:1–8. https://doi.org/10.1016/j.ejim.2021.04.019.
[69] Angeli F, Verdecchia P, Reboldi G. RAAS Inhibitors and Risk of Covid-19. N Engl J Med 2020;383:1990–1. https://doi.org/10.1056/NEJMc2030446.
[70] Verdecchia P, Angeli F, Reboldi G. Angiotensin-converting enzyme inhibitors, angiotensin II receptor blockers and coronavirus. J Hypertens 2020;38:1190–1. https://doi.org/10.1097/HJH.0000000000002469.
[71] Vidovich MI. Transient Brugada-Like Electrocardiographic Pattern in a Patient With COVID-19. JACC Case Rep 2020;2:1245–9. https://doi.org/10.1016/j.jaccas.2020.04.007.
[72] Chang D, Saleh M, Garcia-Bengo Y, Choi E, Epstein L, Willner J. COVID-19 Infection Unmasking Brugada Syndrome. HeartRhythm Case Rep 2020;6:237–40. https://doi.org/10.1016/j.hrcr.2020.03.012.
[73] Dherange P, Lang J, Qian P, Oberfeld B, Sauer WH, Koplan B, Tedrow U. Arrhythmias and COVID-19: A Review. JACC Clin Electrophysiol 2020;6:1193–204. https://doi.org/10.1016/j.jacep.2020.08.002.
[74] Lazzeri C, Bonizzoli M, Batacchi S, Cianchi G, Franci A, Fulceri GE, Peris A. Cardiac Involvment in COVID-19-Related Acute Respiratory Distress Syndrome. Am J Cardiol 2020;132:147–9. https://doi.org/10.1016/j.amjcard.2020.07.010.
[75] Walker C, Peyko V, Farrell C, Awad-Spirtos J, Adamo M, Scrocco J. Pericardial effusion and cardiac tamponade requiring pericardial window in an otherwise healthy 30-year-old patient with COVID-19: a case report. J Med Case Rep 2020;14:158. https://doi.org/10.1186/s13256-020-02467-w.
[76] Bergamaschi L, D'Angelo EC, Paolisso P, Toniolo S, Fabrizio M, Angeli F, Donati F, Magnani I, Rinaldi A, Bartoli L, et al. The value of ECG changes in risk stratification of COVID-19 patients. Ann Noninvasive Electrocardiol 2021;26:e12815. https://doi.org/10.1111/anec.12815.