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Original Article

Electrocardiographic Features and Outcome: Correlations in 124 Hospitalized Patients With COVID-19 and Cardiovascular Events

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Objectives: Electrocardiographic (ECG) changes have been associated with coronavirus disease 2019 (COVID-19) severity. However, the progression of ECG findings in patients with COVID-19 has not been studied. The purpose of this study was to describe ECG features at different stages of COVID-19 cardiovascular (CV) events and to examine the effects of specific ECG parameters and cardiac-related biomarkers on clinical outcomes in COVID-19.

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E-mail address: jiapeng.huang@louisville.edu (J. Huang).
Design: Retrospective, cohort study.
Setting: Major tertiary-care medical centers and community hospitals in Louisville, KY.
Participants: A total of 124 patients with COVID-19 and CV events during hospitalization.
Interventions: None.
Measurements and Main Results: Twelve-lead ECG parameters, biomarkers of cardiac injuries, and clinical outcomes were analyzed with Spearman correlation coefficients and Kruskal-Wallis 1-way analysis of variance. Atrial fibrillation/atrial flutter was more frequent on the ECG obtained at the time of the CV event when compared with admission ECG (9.5% v 26.9%; p = 0.007). Sinus tachycardia was higher in the last available hospital ECG than the CV event ECG (37.5% v 20.4%; p = 0.031). Admission ECG-corrected QT interval was significantly associated with admission troponin levels (R = 0.52; p < 0.001). The last available hospital ECG showed nonsurvivors had longer QRS duration than survivors (114.6 v 91.2 ms; p = 0.026), and higher heart rate was associated with longer intensive care unit length of stay (Spearman p = 0.339; p = 0.032).
Conclusions: In hospitalized patients with COVID-19 and CV events, ECGs at various stages of COVID-19 hospitalization showed significantly different features with dissimilar clinical outcome correlations.

Key Words: COVID-19; SARS-CoV-2; cardiovascular events; mortality; electrocardiogram; ECG

THE CORONAVIRUS disease 2019 (COVID-19) pandemic continues to be the leading cause of mortality and morbidity throughout the world, with more than 229 million infections and 4.7 million deaths as of September 21, 2021.1 In the United States alone, more than 40 million people have been infected, and more than 670,000 people have died.2 Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the novel strain of coronavirus that causes COVID-19, most notably is known to cause severe respiratory disease.3 However, COVID-19 also is known to cause multiorgan dysfunction, with the cardiovascular system being a significant target.4,7 Emerging data suggest that cardiac complications occur in as many as 40% of hospitalized patients.6 Those hospitalized with severe COVID-19 who develop cardiovascular complications have higher mortality, longer length of stay (LOS), and worse prognosis than those who do not experience cardiac complications.8,9

A multitude of heart pathologies have been described in association with SARS-CoV-2 infections. Implicated mechanisms of cardiac involvement include: myocardial ischemia secondary to hypoxic state, COVID-19-associated hypercoagulability and resultant microvascular thrombotic complications, cytokine storm, direct viral inflammatory effect, and drug-induced cardiac damage.10-12 Electrocardiographic (ECG) changes have been correlated with infection severity.7,13-15 Clinical outcome measures, including admission to intensive care,14 mechanical ventilation requirement,14 acute respiratory distress syndrome,7,15-17 acute renal failure requiring renal replacement therapy,7,14 and all-cause mortality,14,16,17 were higher in patients with abnormal ECGs.

The Center of Excellence for Research in Infectious Diseases (CERID) recently analyzed 702 adult patients with COVID-19 hospitalized between March 2020 and June 2020, in a U.S. metropolitan area, and identified 124 patients with cardiovascular (CV) events.18 Patients with CV events had a much higher mortality rate at 45.2% than those without CV events at 8.7%.19 The null hypothesis for this project was there are no significant differences among ECGs at admission, CV events, and discharge (death or out of hospital). The purpose of this study was to investigate the ECG features in patients with COVID-19 and CV events at 3 distinct phases of hospitalization: at admission, during the acute CV event, and approaching discharge or death.

Methods

Study Design and Setting

The clinical data used in this study were from the Burden of COVID-19 study, an observational retrospective cohort database maintained by CERID at the University of Louisville.18-20 The Strengthening the Reporting of Observational Studies in Epidemiology guidelines for reporting observational studies was followed, and the checklist is attached in supplemental material. The primary aim was to describe ECG features at different stages of hospitalization during COVID-19 CV events. The secondary aim was to examine the effects of specific ECG parameters and cardiac-related biomarkers on clinical outcomes in COVID-19.

Human Subjects Protection

The Burden of COVID-19 study, including subsequent research using the database, was approved by the University of Louisville Institutional Review Board (#20-0257). Information from the patients’ electronic health records (EHR) was entered into a secure database (REDCap) and is compliant with the Health Insurance Portability and Accountability Act. Patient data were secure through the use of standard data security measures and approved by the institutional review boards of all participating hospitals to protect and safeguard the private healthcare information of all patients.

Patient Cohort and Study Setting

Data from 702 adult inpatients hospitalized with COVID-19 from March 9, 2020, to June 20, 2020, at all 9 adult hospitals in the Louisville metro area, were reviewed. All hospitalized
patients with a diagnosis of COVID-19—as defined by a positive reverse transcriptase-polymerase chain reaction on the first or the repeat test and/or ground glass opacities on a chest computerized tomography—met the inclusion criteria for the study. Patients with COVID-19 seen in the emergency department who were not admitted as a hospital inpatient were excluded from this study.

Data Collection

Data were abstracted from the EHRs of hospitalized patients diagnosed with COVID-19. A comprehensive data abstraction instrument was developed by physicians, nurses, epidemiologists, biostatisticians, public health professionals, and research assistants who were members of the CERID study group. Trained researchers (P.N., V.S., and H.S.) collected information from the patients’ EHRs on COVID-19 test results, past medical history, social history, symptoms of current illness, medications, physical examination, management and therapies, radiologic and laboratory data, clinical course of hospitalization, complications, and outcomes. Only CV events occurring after admission to the hospital were considered in the analysis. CV events included heart failure, cardiogenic shock, acute myocardial infarction, cardiomyopathy, myocarditis, cardiac arrhythmias (including tachycardia, bradycardia, supraventricular tachycardia, atrial tachycardia, and bundle-branch blocks), cerebrovascular events, pulmonary embolism, pulmonary edema, deep vein thrombosis, and cardiac arrest. Clinical diagnoses of CV events were made independently by individual physicians at each site. The authors planned to use sensitive cardiac injury/function biomarkers (troponin and B-type natriuretic peptide [BNP]) as short-term outcome measures; and mortality, hospital LOS, and intensive care unit (ICU) LOS as long-term outcome measures.

ECG data assumed normal calibration of ECG paper at 25 mm/s and 1 mV equivalent to 10 mm. Results from ECGs were collected from EHRs through abstraction of confirmed 12-lead ECG results by experienced researchers. First ECG was defined as the earliest available ECG in a patient’s EHRs at admission, CV event—triggered ECG was defined as the ECG within 24 hours of a clinically diagnosed CV event, and final ECG was defined as the last recorded ECG before discharge or death.

ECG abnormality was defined as any irregularity in rhythm, left ventricular hypertrophy (LVH), right ventricular hypertrophy (RVH), atrioventricular (AV) block, or ST changes. Rhythm information from ECGs included sinus rhythm, sinus tachycardia, atrial fibrillation, atrial flutter, AV blocks (none, first-degree block, second-degree type I heart block, second-degree type II heart block, third-degree heart block), left bundle-branch block, and right bundle-branch block. Collected ECG parameters included P-R segment duration (normal range, 120-200 ms), QRS duration (normal range, 80-100 ms), corrected QT interval (QTc), presence of pathologic Q-wave (>40 ms wide, >2 mm deep, or >25% of QRS depth), ST-segment elevation, and depression indicative of ischemia (voltage >0.1 mV greater than or less than baseline). Other measurements for analysis included evidence of LVH using Sokolov-Lyon criteria (S wave depth in precordial lead V1 plus tallest R wave height in precordial leads V5-V6 >35 mm) and evidence of RVH (right axis deviation >90° or 110° with larger R and smaller S waves in leads V1 and V2).

Laboratory data included the first and highest (peak) levels of troponin, as well as BNP and N-terminal pro BNP (NT-pro BNP) levels. Measurements of BNP and NT-pro BNP were converted to 1 standard unit of measurement for comparison because hospitals used either BNP or NT-pro BNP, not both. BNP measurement of 1 pg/mL is equivalent to 0.289 pmol/L, and NT-pro BNP measurement of 1 pg/mL is equivalent to 0.118 pmol/L.

Clinical Outcome Variables

Clinical outcome variables included mortality (date of death and number of days from hospital admission to mortality), hospital LOS, and ICU LOS.

Data Analysis

Descriptive statistics were reported; continuous variables were summarized as mean and standard deviation (SD), and categorical variables were summarized as counts and percentages. To examine the association between ECG parameters and troponin/BNP values, Spearman correlation coefficients were used to evaluate the association between 2 continuous variables, and Kruskal–Wallis 1-way analysis of variance was conducted to examine the association between a categorical variable and a continuous outcome variable. To examine whether ECG parameters were associated with mortality (eg, patients discharged alive or not), Mann-Whitney U tests were used for continuous ECG parameters and chi-square tests or Fisher exact tests for categorical ECG parameters. Generalized mixed-effect models were used to examine whether ECG parameters changed over time. In particular, logistic mixed-effect models were used to examine the time effect for categorical ECG parameters, and linear mixed-effect models were used to examine time effect for continuous ECG parameters. In the generalized linear mixed-effect models, each subject was considered as a random effect. The intraindividual variations were captured by the random effects, and the interindividual variations were captured by the individual-level covariates; p Values <0.05 were considered statistically significant. Statistical analyses were conducted using R version 4.0.2 software (R Foundation for Statistical Computing). This complex data analysis was carried out by a PhD student in biostatistics (Q.X.) under the supervision of Maiying Kong, professor in bioinformatics and biostatistics at the University of Louisville.

Results

The sample population consisted of 702 hospitalized patients with COVID-19, 124 of whom had a CV event. Among the 124 patients with a CV event, 22 patients (17.7%)
had heart failure, 19 (15.3%) had cardiac arrest, 14 (11.3%) had cardiogenic shock, 15 (12.1%) had acute myocardial infarction, 12 (9.7%) had pulmonary edema, 54 (43.5%) had new serious arrhythmias, 19 (15.3%) had acute worsening of long-term arrhythmia, 7 (5.6%) had cerebrovascular accidents, 8 (6.5%) had pulmonary embolism, 2 (1.6%) had myocarditis, and 6 (4.8%) had deep venous thrombosis. Preexisting cardiac comorbidities in hospitalized patients with COVID-19 and CV events and in hospitalized patients with COVID-19 without CV events are summarized in Supplementary Table 1. The group with CV events showed significantly higher incidences of all preexisting cardiac comorbidities than the group without CV events except deep venous thrombosis. Among the 124 patients, 86 required ICU care. Fifteen patients received noninvasive mechanical ventilation, and 69 patients needed invasive mechanical ventilation.

Table 1 summarizes the ECG parameters in first, CV event-triggered, and final ECGs. Normal sinus rhythm was significantly more common in the first ECG compared with the CV event-triggered ECG (42.6%; p = 0.023). Atrial fibrillation or atrial flutter was more frequent in the first ECG compared with the CV event-triggered ECG (29.8%; p = 0.007). Sinus tachycardia was significantly more frequent in the final ECG than in the CV event-triggered ECG (37.5% vs. 20.4%; p = 0.031). Interestingly, the authors found that QRS duration was significantly longer in the CV event-triggered ECG (26.9%; p = 0.031). Heart rate, P-R interval, and QRS duration; Supplemental Table 5).

Table 2, Supplemental Table 2, and Supplemental Table 3 show the associations among the ECG parameters of first, event-triggered, and final ECGs and mortality, ICU LOS, and hospital LOS. For the first ECG, hospital and ICU LOS were significantly longer for patients with normal sinus rhythm than in those with atrial fibrillation or atrial flutter (11.45 vs. 7.61 days for hospital LOS and 6.75 vs. 0.62 days for ICU LOS, respectively; Table 3). For the final ECG, nonsurvivors had much longer QRS duration than survivors (114.6 vs. 91.2 ms; p = 0.026; Supplemental Table 2), and a higher heart rate was significantly associated with longer ICU LOS with a Spearman correlation coefficient of 0.339 (p = 0.032; Supplemental Table 3).

First troponin values were compared between patients with and without an ECG abnormality in the first ECG. There was no significant difference in first troponin level among those with and without an ECG abnormality (Table 4). Supplemental Table 4 showed the correlation coefficients for continuous ECG parameters of the first ECG. QTc was significantly associated with the first troponin levels (R value = 0.52, p < 0.001).

Table 3 showed a comparison of peak troponin values between patients with and without ECG abnormality in rhythm, LVH, RVH, AV block, or ST changes. Peak troponin levels of patients with atrial fibrillation or atrial flutter were significantly lower than those with normal sinus rhythm (0.073 ± 0.1 vs. 0.681 ± 1.3; p = 0.043) (Table 3). There were no significant correlations between peak troponin levels and CV event-triggered ECG parameters (heart rate, P-R interval, QTc, and QRS duration; Supplemental Table 5).

The effects of the first troponin, peak troponin, and BNP levels on mortality, ICU LOS, and hospital LOS for all 702 patients are summarized in Table 5. Levels of first troponin (1.256 ± 0.116 ± 0.6 ng/mL; p < 0.001), peak troponin (0.389 ± 0.311 ± 0.8 ng/mL; p < 0.001), and BNP (1733.718 ± 4536.2 ± 565.063 ± 2909 pmol/L; p = 0.011) were higher in patients who died in the hospital. First troponin levels were significantly correlated with both hospital LOS (R = 0.165; p < 0.001) and ICU LOS (R = 0.172; p < 0.001). Peak troponin levels were significantly correlated with ICU LOS (R = 0.301; p = 0.001). BNP was significantly correlated with both hospital LOS (R = 0.204; p < 0.001) and ICU LOS (R = 0.212; p < 0.001).

Table 1
Summarized ECG Parameters in the First ECGs, Event-Triggered ECGs, and Final ECGs

| Sample sizes | First ECG | ET ECG | Final ECG | p Value for First versus ET | p Value for Final versus ET |
|--------------|-----------|--------|-----------|-----------------------------|-----------------------------|
| Rhythm, n (%) |           |        |           |                             |                             |
| Normal sinus  | 44 (59.5%) | 46 (42.6%) | 17 (42.5%) | 0.023*                      | 0.919                       |
| Atrial Fibrillation/Flutter | 7 (9.5%) | 29 (26.9%) | 5 (12.5%) | 0.007*                      | 0.167                       |
| Sinus tachycardia | 20 (27.0%) | 22 (20.4%) | 15 (37.5%) | 0.285                       | 0.031*                      |
| Other         | 3 (4.1%)  | 11 (10.2%) | 3 (7.5%)   | 0.155                       | 0.056                       |
| Heart rate, mean (SD), bpm | 94 (22.7) | 100.31 (30.3) | 95.9 (24) | 0.081                       | 0.530                       |
| P-R interval, mean (SD), ms | 169.3 (73.3) | 156.9 (35.5) | 144.9 (38) | 0.096                       | 0.268                       |
| QTc, mean (SD), ms | 457.7 (38.6) | 469.4 (40.7) | 463.8 (46.7) | 0.080                       | 0.317                       |
| QRS duration, mean (SD), ms | 104.0 (26.7) | 107.4 (30.2) | 105.6 (30.3) | 0.898                       | 0.047*                      |
| Q-wave, n (%) | 0 (0%)    | 1 (0.9%)  | 0 (0%)    | 0.991                       | 0.996                       |
| LVH, n (%)    | 8 (10.8%) | 9 (8.3%)  | 3 (7.5%)  | 0.103                       | 0.695                       |
| RVH, n (%)    | 1 (1.4%)  | 0 (0%)    | 0 (0%)    | 0.999                       | 0.995                       |
| AV block, n (%) | 21 (28.4%) | 34 (31.5%) | 7 (17.5%) | 0.441                       | 0.018*                      |
| ST changes, n (%) | 3 (4.1%) | 10 (9.3%) | 6 (15%)   | 0.259                       | 0.252                       |

Abbreviations: AV, atrioventricular; ECG, electrocardiogram; ET, event-triggered; LVH, left ventricular hypertrophy; RVH, right ventricular hypertrophy.  
* p Value <0.05.
Associations of first troponin, peak troponin, and BNP with mortality, ICU LOS, and hospital LOS among the 124 patients with CV events are summarized in Supplemental Table 6. However, no significant correlations with any of these 3 main clinical outcomes were observed.

Discussion

Comprehensive analysis of ECGs in 124 patients with CV events demonstrated distinct features of the first ECG (on admission), CV event—triggered ECG (within 24 hours of CV event), and final ECG (last ECG before discharge or death). Atrial fibrillation/flutter was the most common arrhythmia during CV events, and sinus tachycardia was the most common rhythm in the final ECG. QRS duration was longer, and AV block was more commonly present in the CV event—triggered ECGs.

Two systematic reviews of ECG findings in patients with COVID-19 recently have been published.25,26 Mehraeen et al. included 20 articles and found ST-T abnormalities—namely ST elevation—were the most observed ECG findings, but the relationship with myocardial injuries is debatable. Garcia-Zamora et al. performed a meta-analysis of 28 studies, with 12,499 participants, and found that the overall prevalence of cardiac arrhythmias was 10.3%, with the most common arrhythmias documented during hospitalization being supraventricular arrhythmias (6.2%), followed by ventricular arrhythmias (2.5%). The incidence of cardiac arrhythmias was higher among critically ill patients (relative risk, 12.1; 95% confidence interval [CI], 8.5-17.3) and among nonsurvivors (relative risk, 3.8; 95% CI, 1.7-8.7). However, neither of these studies analyzed ECG parameters based on the timing of ECG or how ECGs change during hospitalization in patients with COVID-19. This information is critical to understand how cardiac injuries evolve in hospitalized patients with COVID-19. Therefore, this study separated ECGs into 3 important phases—admission, within 24 hours of CV events, and near discharge/death—to study distinct ECG features and their progression. Because troponin level reflects and quantifies acute myocardial damage, the authors decided to correlate the first ECG parameters with the first troponin level and CV

Table 2
Summary of Statistics Among ECG Parameters at Each Time Point (First, Event-Triggered, and Final ECG) and Outcome Variables in Terms of ICU Length of Stay and Hospital Length of Stay

| Rhythm Type | First ECG | Event-Triggered ECG | Final ECG |
|-------------|-----------|---------------------|----------|
|              | n (% IQR) | Hospital LOS, median (IQR) |      | n (% IQR) | Hospital LOS, median (IQR) |      | n (% IQR) | Hospital LOS, median (IQR) | p Value |
| All rhythms  | 74 (1.19, 18.18) | 108 (5.87, 18.14) | 40 (1.19, 17.95) | 0.004 |
| Normal sinus | 44 (7.13, 18.09) | 46 (4.79, 14.51) | 17 (5.17, 18.86) | 0.088 |
| Atrial fibrillation/flutter | 7 (5.97, 7.70) | 29 (7.35, 16.45) | 5 (8.92, 12.02) | 0.076 |
| Sinus tachycardia | 20 (9.34, 12.51) | 22 (5.34, 14.66) | 15 (7.53, 34.43) | 0.331 |
| Other | 3 (5.36, 7.42) | 11 (6.10, 18.91) | 3 (7.26, 17.19) | 0.099 |
| All rhythms | 74 (1.91, 12.33) | 108 (0, 11.11) | 40 (3.54, 13.22) | 0.05 |
| Normal sinus | 44 (1.82, 12.94) | 46 (0.11, 11.12) | 17 (0.72, 11.05) | 0.261 |
| Atrial fibrillation/flutter | 7 (0.26, 2.64) | 29 (0.98, 19.32) | 5 (7.08, 11.90) | 0.271 |
| Sinus tachycardia | 20 (5.98, 16.27) | 22 (0, 11.51) | 15 (5.92, 32.17) | 0.059 |
| Other | 3 (2.15, 3.71) | 11 (0.58, 8.52) | 3 (5.62, 16.92) | 0.524 |

Abbreviations: ECG, electrocardiogram; ICU, intensive care unit; IQR, interquartile range; LOS, length of stay.

< Overall median (IQR).
† Overall p value comparing 4 different rhythms.
‡ p Value <0.05.
§ p Value compared with normal sinus rhythm.

Table 3
Comparisons of the Peak Troponin Level Between Patients With Abnormality and Those Without Abnormality Based on the Event-Triggered ECG Abnormality

| Rhythm Type | Event-Triggered ECG | Peak Troponin With Abnormality, ng/mL (mean ± SD) | Peak Troponin Without Abnormality, ng/mL (mean ± SD) | p Value |
|-------------|---------------------|-------------------------------------------------|-------------------------------------------------|---------|
| AF/flutter   | 29 (26.9%) | 0.073 ± 1 | 0.681 ± 1.3 | 0.0430 |
| Sinus tachycardia | 22 (20.4%) | 0.614 ± 1.4 | 0.681 ± 1.3 | 0.7121 |
| Others       | 11 (10.2%) | 0.157 ± 0.2 | 0.681 ± 1.3 | 0.1654 |
| LVH          | 9 (8.3%) | 0.05 ± NA | 0.506 ± 1.1 | 0.4102 |
| AV block     | 34 (31.5%) | 0.365 ± 0.7 | 0.556 ± 1.2 | 0.6647 |
| ST changes   | 10 (9.3%) | 0.922 ± 1.9 | 0.433 ± 1 | 0.8219 |

Abbreviations: AF, atrial fibrillation; AV, atrioventricular; LVH, left ventricular hypertrophy; NA, not available owing to only 1 observation under the conditions; SD, standard deviation.

* p Value <0.05.
event—triggered ECG parameters with peak troponin, indicative of the most severe cardiac injuries during hospitalization. This analysis might provide insights into how cardiovascular injuries occur and develop during hospitalization in patients with COVID-19.

ECG abnormalities commonly seen in cardiac injury are arrhythmia, ST elevation, P-R depression, new-onset bundle-branch block, QT prolongation, pseudoinfarct pattern, premature ventricular complexes, bradyarrhythmias, and ventricular tachycardia. Consistent with previous studies, this study found atrial fibrillation or flutter to be the most common arrhythmia during CV event—triggered ECG (26.9%). However, atrial fibrillation or flutter was much lower on first ECG (9.5%) and final ECG (12.5%). A recent COVID-19 study found atrial fibrillation or flutter to be the most frequently reported serious arrhythmia, was associated with higher troponin values, and carried a higher mortality rate than other rhythms. In the present study, AV block was also significantly higher in CV event—triggered ECG (31.5%) compared with hospital or ICU LOS. Furthermore, this study found that QRS duration on final ECG was significantly longer in nonsurvivors than in survivors among hospitalized patients with COVID-19.

No correlation was found between CV event—triggered or final ECG and either hospital or ICU LOS. One possible explanation could be early mortality with atrial arrhythmia. QRS duration longer than 120 ms was associated with worse clinical outcomes and higher levels of myocardial injury biomarkers in COVID-19. Prolonged QRS could reflect active myocardial injury during CV events caused by the direct impact of SARS-CoV-2 on the cells. A wide QRS complex previously has been associated with increased mortality risk in patients without COVID-19. The authors’ findings further confirmed the importance of QRS duration in predicting mortality in patients with COVID-19. CV event—triggered ECG demonstrated significantly longer QRS duration than that on the first or final ECGs. Furthermore, this study found that QRS duration on final ECG was significantly longer in nonsurvivors than in survivors among hospitalized patients with COVID-19.

Among all the parameters reviewed on the first ECGs, only QTc showed a significant correlation with the first troponin level. A recent meta-analysis found that the prevalence of QTc > 500 ms was 12.3% in patients with COVID-19. QTc interval prolongation was found to be associated with increased COVID-19 severity and mortality. However, the risk of torsades de pointes was not increased in hospitalized patients with COVID-19 who showed a marked prolongation of QTc interval. In this study, the authors did not find any correlation between ECG parameters and peak troponin levels among CV event—triggered ECGs. This might suggest that the CV event—triggered ECG parameters are not useful predictors of further outcomes.

Table 4

| First ECG Abnormality | n (%) | First Troponin Level With Abnormality, ng/mL (mean ± SD) | First Troponin Level Without Abnormality, ng/mL (mean ± SD) | p Value |
|-----------------------|-------|----------------------------------------------------------|----------------------------------------------------------|---------|
| Rhythm: AF/flutter    | 7 (9.5%) | 0.109 ± 0.1                                             | 0.234 ± 0.8                                             | 0.2374  |
| Rhythm: sinus tachycardia | 20 (27.0%) | 0.096 ± 0.1                                             | 0.234 ± 0.8                                             | 0.3221  |
| Rhythm: others       | 3 (4.1%) | 0.03 ± 0                                                  | 0.234 ± 0.8                                             | 0.1855  |
| LVH                   | 8 (10.8%) | 0.082 ± 0.1                                             | 0.187 ± 0.7                                             | 0.6769  |
| RVH                   | 1 (1.4%) | 0.03 ± NA                                                 | 0.177 ± 0.7                                             | 0.7558  |
| AV block              | 21 (28.4%) | 0.164 ± 0.2                                             | 0.179 ± 0.8                                             | 0.0788  |
| ST changes            | 3 (4.1%) | 0.033 ± 0                                                 | 0.181 ± 0.7                                             | 0.3309  |
|                       |        |                                                          |                                                         |         |

Abbreviations: AF, atrial fibrillation; AV, atrioventricular; ECG, electrocardiogram; LVH, left ventricular hypertrophy; NA, not available; RVH, right ventricular hypertrophy; SD, standard deviation.

Table 5

| First Troponin Level | Alive(Mean ± SD) | p Value | Spearman Correlation(LOS) | p Value(LOS) | Spearman Correlation (ICU LOS) | p Value(ICU LOS) |
|----------------------|------------------|---------|----------------------------|--------------|-------------------------------|------------------|
| First troponin, ng/mL | 1.256 ± 1        | <0.001 *| 0.165                     | <0.001 *     | 0.172                         | <0.001 *         |
| Peak troponin, ng/mL | 0.389 ± 1        | <0.011  | 0.17                      | 0.072 *      | 0.301                         | 0.001 *          |
| BNP, pmol/L          | 1733.718 ± 4536.2| <0.001 *| 0.204                     | <0.001 *     | 0.212                         | <0.001 *         |
|                      |                  |         |                            |              |                               |                  |

Abbreviations: BNP, B-type natriuretic peptide; ICU, intensive care unit; LOS, length of stay; SD, standard deviation.

* p Value < 0.05.
It has been demonstrated that ECG ST-T segment alterations are the most commonly reported ECG anomaly in patients with COVID-19,13,14,17,33 and are more frequent among patients with severe COVID-19.13,40,41 Barman et al. showed that ST-T changes on admission ECG were closely associated with the severity of COVID-19 infection.13 The present study found ST changes on the first ECGs in 4.1% of patients with CV events, and on CV event–triggered ECGs in 9.3%. However, there was no significant correlation with either first or peak troponin level.

Sinus tachycardia was reported to be the most common arrhythmia in patients with COVID-19,13,14,17,33 and was more frequent in nonsurvivors. This study found that heart rate on the final ECG was significantly correlated with ICU LOS. This could indicate higher levels of stress due to sepsis, hypovolemia, pulmonary embolism, anxiety, or mechanical ventilation.

Research on ECG alterations and hospital LOS is limited. Abrams et al. compared the characteristics of patients with COVID-19 who died of arrhythmias with those who died of other causes, and there was no statistically significant difference in LOS between the 2 groups (median 5 vs 4 days; p = 0.76).42 In addition to ECG findings, cardiac involvement can be detected by multiple laboratory markers, including troponin and BNP. Higher BNP values have been associated with abnormal ECG14 and higher in-hospital mortality.17 Troponin levels were higher in nonsurvivors than in survivors,33 as well as in patients with severe illness compared with those with nonsevere COVID-19.40 For the entire patient cohort (patients with and without CV events), the present study found that the first troponin level, peak troponin level, and BNP were all significantly associated with mortality and ICU LOS. First troponin level and BNP were also significantly associated with hospital LOS. However, the authors did not find any significant correlations among first troponin level, peak troponin level, or BNP and mortality, ICU LOS, or hospital LOS among patients with CV events. These results were surprising yet explicable. If cardiac injury has been ongoing, additional troponin and BNP values could not help further prediction of clinical outcomes. Another explanation could be patients with CV events shared common risk factors that are more dominant to determine the clinical outcomes. It also could be possible that SARS-CoV-2 virus induces myocardial injury through a different mechanism that is not dependent on the level of cardiac biomarkers. This might imply that clinicians should reconsider ordering additional troponin and BNP tests, as they did not effectively predict outcomes in patients with COVID-19 and CV events.

There were limitations to this retrospective study. The results may not be generalizable to all patients with COVID-19, as they may have significantly different characteristics compared with patients hospitalized with COVID-19; hence, the external validity of the study is limited to hospitalized patients. Studies with retrospective design may bias the true incidence and influence of ECG abnormalities, as well as their prognostic value as predictors of clinical outcomes. To reduce these confounders and risk of bias in future research, large-scale prospective studies are needed to determine whether ECG abnormalities play an important role in predicting adverse clinical COVID-19 outcomes.

**Conclusion**

The simplicity and availability of the 12-lead ECG make it a potentially valuable predictive tool in the risk stratification and management of patients with COVID-19. This study shed light on the importance of ECG findings in hospitalized patients with CV events. The authors found that ECGs at various stages of COVID-19 hospitalization showed significantly different features with dissimilar clinical outcome correlations.

**Declaration of Competing Interest**

None.

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**Supplementary materials**

Supplementary material associated with this article can be found in the online version at doi:10.1053/j.jvca.2022.01.011.

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