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ABSTRACT

OBJECTIVES This study aimed to assess the association of new right heart strain patterns on presenting 12-lead electrocardiogram (RHS-ECG) with outcomes in patients hospitalized with COVID-19.

BACKGROUND Cardiovascular comorbidities and complications, including right ventricular dysfunction, are common and are associated with worse outcomes in patients with COVID-19. The data on the clinical usefulness of the 12-lead ECG to aid with prognosis are limited.

METHODS This study retrospectively evaluated records from 480 patients who were consecutively admitted with COVID-19. ECGs obtained at presentation in the emergency department (ED) were considered index ECGs. RHS-ECG was defined by any new right-axis deviation, $S_1Q_3T_3$ pattern, or ST depressions with T-wave inversions in leads V_1 to V_3 or leads II, III, and aVF. Multivariable logistic regression was performed to assess whether RHS-ECGs were independently associated with primary outcomes.

RESULTS ECGs from the ED were available for 314 patients who were included in the analysis. Most patients were in sinus rhythm, with sinus tachycardia being the most frequent dysrhythmia. RHS-ECG findings were present in 40 (11%) patients. RHS-ECGs were significantly associated with the incidence of adverse outcomes and an independent predictor of mortality (adjusted odds ratio [adjOR]: 15.2; 95% confidence interval [CI]: 5.1 to 45.2; $p < 0.001$), the need for mechanical ventilation (adjOR: 8.8; 95% CI: 3.4 to 23.2; $p < 0.001$), and their composite (adjOR: 12.1; 95% CI: 4.3 to 33.9]; $p < 0.001$).

CONCLUSIONS RHS-ECG was associated with mechanical ventilation and mortality in patients admitted with COVID-19. Special attention should be taken in patients admitted with new signs of RHS on presenting ECG. (J Am Coll Cardiol EP 2020;■:■–■) © 2020 by the American College of Cardiology Foundation.

Coronavirus Disease 2019 (COVID-19) is caused by the novel severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2). It was first discovered in late 2019 in Wuhan, China, and has since caused a global pandemic affecting >25 million people worldwide and 6 million in the United States (1).

Several risk factors have been reported to be associated with COVID-19 severity and outcomes. Emerging information has revealed that cardiovascular complications, including right ventricular (RV) dysfunction and cor pulmonale, are common and confer worse outcomes in patients admitted with COVID-19 (2,3). Clinical tools such as troponin levels, 12-lead electrocardiograms (ECGs), and echocardiograms are being used to aid with diagnosis and prognosis, although there is limited information due to lack of data. This study aimed to describe the

ABBREVIATIONS AND ACRONYMS

adjOR = adjusted odds ratio

AKI = acute kidney injury

ARDS = acute respiratory distress syndrome

CI = confidence interval

ED = emergency department

ECG = electrocardiogram

IQR = interquartile range

RHS = right heart strain

RHS-ECG = new right heart strain patterns on presenting 12-lead electrocardiogram

RV = right ventricular

SARS-CoV-2 = severe acute respiratory syndrome coronavirus-2

SPO₂/FiO₂ = ratio of peripheral capillary oxygen saturation to the fraction of inspired oxygen

characteristics and outcomes of patients admitted with COVID-19 in a tertiary referral center emergency department (ED) and to assess whether new right heart strain patterns on presenting ECGs (RHS-ECGs) were associated with specific outcomes.

METHODS

COHORT PATIENT POPULATION. We retrospectively evaluated the records of 480 patients consecutively admitted with COVID-19 at a tertiary care center in the metropolitan Detroit area between March 9 and April 1, 2020. Patients were included if they were diagnosed with COVID-19 and had a baseline ECG recorded in the ED.

COVID-19 was diagnosed using molecular diagnostic testing of the nasopharynx or bronchial secretions using reverse transcription polymerase chain reaction to identify SARS-CoV-2 RNA. Our method was validated against the Centers for Disease Control and Prevention reference method to meet or exceed the level of detection required under the Food and Drug Administration Emergency Use Authorization guidelines.

DEFINITION OF VARIABLES AND OUTCOMES. Demographics, vital signs, comorbid conditions, laboratory, and radiological data at hospital admission were manually collected from the electronic health records (**Table 1** and Supplemental Table 1). Symptoms were deemed positive if endorsed within 24 h of presentation. Baseline results referred to initial blood samples collected in the ED or the first values within 24 h of admission. Comorbid conditions were identified based on admission diagnoses.

ECGs from the ED were read by G.S. and S.P., who were blinded to data and outcomes. ECG signs suggestive of RHS were defined by any of the following: new right-axis deviation, $S_1Q_3T_3$ pattern; or ST depressions with T-wave inversions in leads V_1 to V_3 and leads II, III, aVF not present on a previous ECG. Cardiac injury on 12-lead ECG was defined by any ST elevation, depression, or T-wave flattening or inversion that was not due to repolarization abnormalities.

Cardiac injury via laboratory data was defined by a high-sensitivity troponin level >99th percentile (4,5) (>18 ng/l in our assay). The degree of hypoxia was measured as the ratio of peripheral capillary oxygen saturation (SpO_2) to the fraction of inspired oxygen (FiO_2) ($SPO_2: FiO_2$), in accordance with the original mSOFA (Modified Sequential Organ Failure Assessment) investigations (6). SpO_2 values were obtained from pulse oximetry ED vital logs or arterial blood

gases. For those who were not intubated, FiO_2 was estimated by multiplying liter flow per minute by 0.03 and adding that to 0.21, in accordance with original mSOFA investigations (6).

The primary outcomes were mortality, need for mechanical ventilation, and their composite. The secondary outcomes were acute kidney injury (AKI), need for renal replacement therapy, acute respiratory distress syndrome (ARDS), and different composites of the mentioned outcomes. ARDS was defined according to the Berlin definition (7), and AKI was defined according to the Kidney Disease: Improving Global Outcomes criteria for creatinine (8).

The cohort was categorized based on the presence of RHS-ECG (**Table 1**) and the primary outcomes (Supplemental Table 1).

STATISTICAL ANALYSIS. The clinical data elements of different groups were compared using the chi-square test for categorical variables and analysis of variance or Kruskal-Wallis test for continuous variables based on the normality of the data. Univariate analysis was first done to identify the significant variables associated with the designed primary outcome. Multivariable logistic regression analysis was then performed to identify significant predictors of that outcome. Candidate variables for model inclusion included statistically and clinically relevant variables associated with COVID-19 critical illness (9,10) and those with a p value ≤0.05 on univariable analysis for our primary outcomes. The model exit criteria was p ≥ 0.1.

This study was approved by the institutional review board (#13774), and informed consent was waived.

RESULTS

ECGs from the ED were available for 314 of 480 patients and were included in the analysis. Almost all patients were in sinus rhythm, with sinus tachycardia being the most frequent dysrhythmia. The mean age was 60 ± 14 years, and 151 (48%) were women. There were 34 (11%) patients with new RHS-ECGs that were not present on previous ECGs.

BASELINE CLINICAL AND LABORATORY CHARACTERISTICS OF PATIENTS WITH COVID-19 ACCORDING TO PRESENCE OF ECG SIGNS OF RHS. There were several differences between patients with RHS-ECGs and those without. Patients with RHS-ECGs were older and statistically more likely to have a history of cerebrovascular disease, chronic obstructive pulmonary disease, and be smokers (all p < 0.05). These patients were also more likely to have risk factors for cardiovascular disease

TABLE 1   Clinical Characteristics of Patients According to the Presence or Absence of Signs of RHS on the Presenting 12-Lead ECG

		RHS-ECG		
Variable	Overall (N = 314)	With (n = 34)	Without (n = 280)	p Value
Demographic characteristic				
Age (yrs)	60 ± 15	65 ± 15	59 ± 15	0.021
No. of patients ≥65 yrs	117 (37)	20 (59)	97 (35)	0.006
Sex				
Women	151 (48)	19 (56)	132 (47)	0.335
Men	163 (52)	15 (44)	148 (53)	
Body mass index	33 (29–41)	34 (30–41)	33 (29–42)	0.164
Vital signs and oxygenation on admission				
Mean arterial pressure (mm Hg)	80 (72–88)	80 (71–91)	80 (72–88)	0.525
SPO_2:FiO_2 ratio	359 (301–452)	333 (239–405)	359 (311–452)	0.053
Symptoms on admission				
Chest pain	64 (20)	11 (32)	53 (19)	0.067
Shortness of breath	220 (70)	28 (82)	192 (69)	0.098
Cough	234 (75)	25 (74)	209 (75)	0.888
Comorbid conditions				
Hypertension	232 (74)	25 (74)	207 (74)	0.960
Diabetes mellitus	151(48)	21 (62)	130 (46)	0.091
Coronary artery disease	47 (15)	8 (24)	39 (14)	0.138
Cerebrovascular disease	13 (4)	4 (12)	9 (3)	0.019
Atrial fibrillation/flutter	13 (4)	3 (9)	10 (4)	0.147
Chronic kidney disease	122 (39)	17 (50)	105 (38)	0.158
Chronic obstructive pulmonary disease	36 (12)	10 (29)	26 (9)	0.001
Asthma	45 (14)	3 (9)	42 (15)	0.332
Obstructive sleep apnea	31 (10)	3 (9)	28 (10)	0.828
Chronic hypoxic respiratory failure	9 (3)	2 (6)	7 (3)	0.264
Smoking history	112 (36)	18 (53)	94 (34)	0.026
Immunosuppression	21 (7)	2 (6)	19 (7)	0.842
Laboratory data				
Creatinine (mg/dl)	0.9 (0.8–1.2)	1.1 (0.7–1.3)	0.9 (0.8–1.1)	0.425
White blood cell count (K/μl)	5.8 (4.2–7.0)	6.7 (5.7–8.6)	5.6 (4.1–6.9)	0.005
Lymphocyte count (K/μl)	0.9 (0.7–1.2)	0.8 (0.6–1.3)	0.9 (0.7–1.2)	0.812
Hemoglobin (g/dl)	13.0 (12.0–14.5)	12.5 (11.2–14.1)	13.1 (12–14.5)	0.521
Platelet count (K/μl)	197 (158–245)	173 (157–256)	197 (163–246)	0.644
Aspartate aminotransferase (IU/l)	31 (23–52)	29 (22–74)	31 (24–52)	0.131
Alanine aminotransferase (IU/l)	21 (13–38)	21 (13–44)	20 (13–35)	0.769
Total bilirubin (mg/dl)	0.5 (0.4–0.8)	0.7 (0.4–0.9)	0.5 (0.4–0.8)	0.718
Albumin (mg/dl)	3.6 (3.3–3.8)	3.5 (3.3–3.7)	3.6 (3.3–3.8)	0.157
High-sensitivity troponin (ng/l)	10 (5–21)	21 (12–37)	9 (4–21)	0.935
Cardiac injury*	117 (37)	21 (62)	96 (34)	0.002
Brain natriuretic peptide (pg/ml)	36 (18–79)	77 (36–183)	32 (16–71)	0.758
Elevated brain natriuretic peptide†	94 (39)	16 (57)	78 (37)	0.040
Lactate dehydrogenase (IU/l)	319 (257–415)	328 (269–450)	316 (252–395)	0.157
Ferritin (ng/ml)	331 (159–810)	409 (237–875)	329 (155–837)	0.685
D-dimer (μg/ml)	0.89 (0.49–1.46)	1.12 (0.48–2.815)	0.78 (0.49–1.37)	0.009
ECG characteristics				
Sinus rhythm	273 (87)	32 (94)	241 (86)	0.189
Sinus tachycardia	100 (32)	12 (35)	88 (31)	0.648
Atrial fibrillation/flutter	9 (3)	0	9 (3)	0.289
Heart rate	103 (91–111.75)	101 (90–107)	103 (91–112)	0.677
QRS duration	84 (78–97.5)	118 (80–145)	84 (78–92)	0.044
QTc duration	438 (421–461)	449 (429–493)	435 (420–457)	<0.001
Any injury pattern	33 (11)	4 (12)	29 (10)	0.800
Prolonged QTc	82 (26)	18 (53)	64 (23)	<0.001
First-degree AV block	11 (4)	1 (3)	10 (4)	0.936

TABLE 1 Continued

Variable	Overall (N = 314)	RHS-ECG		p Value
		With (n = 34)	Without (n = 280)	
Chest imaging findings				
Normal	47 (15)	2 (6)	45 (16)	0.099
Unilateral pneumonia	44 (14)	4 (12)	40 (14)	
Bilateral pneumonia	94 (30)	16 (47)	78 (28)	
Multifocal pneumonia	129 (41)	12 (35)	117 (42)	

Values are mean ± SD, n (%), and medians (interquartile ranges). *Cardiac injury as defined by a troponin level above the 99th percentile (18 ng/l). †Elevated brain natriuretic peptide as defined by a level >50 pg/l.

AV = atrioventricular; ECG = electrocardiography; RHS-ECG = new right heart strain patterns on presenting 12-lead electrocardiogram; SPO$_2$/FiO$_2$ = ratio of peripheral capillary oxygen saturation to the fraction of inspired oxygen.
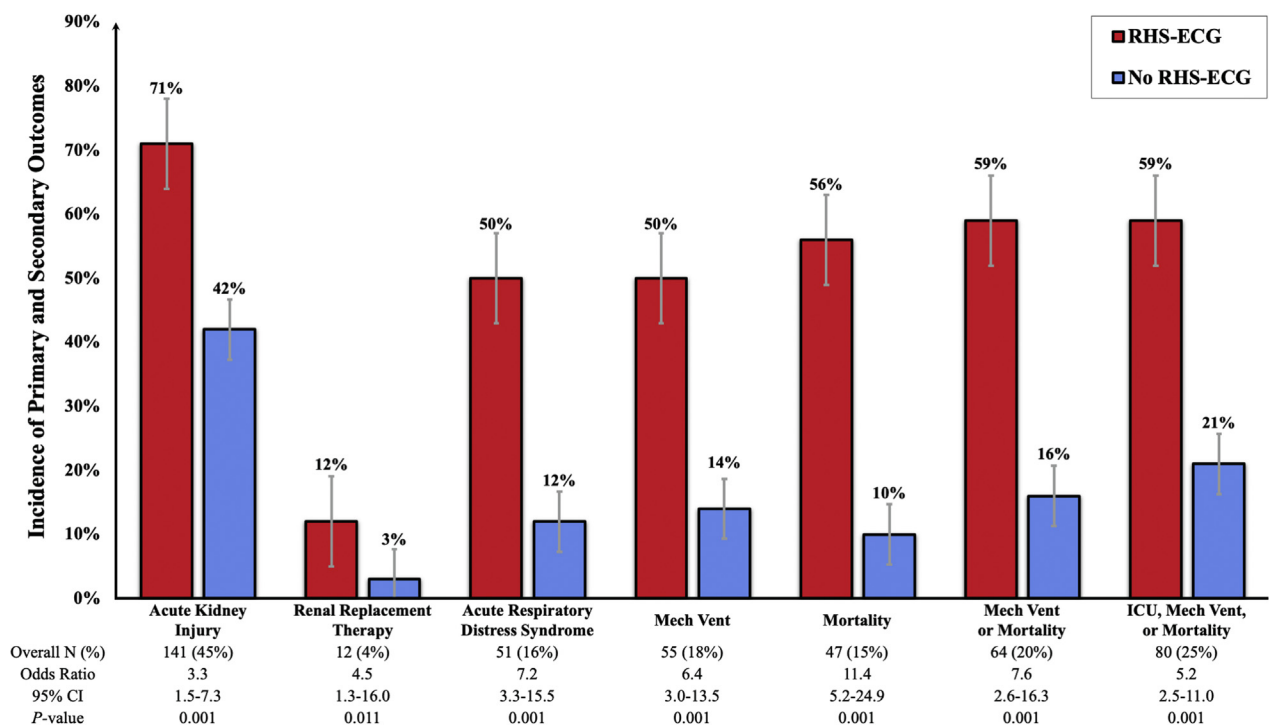
(diabetes mellitus, coronary artery disease, chronic kidney disease); however, the difference did not reach statistical significance (Table 1).

Baseline laboratory data, including inflammatory markers, were compared between both groups. Upon admission, patients with RHS-ECGs had higher D-dimer levels (1.12 μg/ml vs. 0.78 μg/ml; p = 0.009), but there were no differences in baseline lactate dehydrogenase and ferritin levels (Table 1). Patients with RHS-ECGs were more likely to have elevated

brain natriuretic peptide levels in addition to cardiac injury as defined by a troponin level >99th percentile. There was no statistical difference in chest imaging findings (Table 1).

Among the 40 patients who had new ECG patterns suggestive of RHS, there were 17 (54%) with new right-axis deviation, 13 (38%) with $S_1Q_3T_3$ patterns, and 11 (32%) with ST depressions with T-wave inversions in leads V_1 to V_3 or leads II, III, and aVF that were not present on previous ECGs. In addition, 10

FIGURE 1 Incidence of Different Outcomes According to the Presence of RHS Patterns on Presenting 12-Lead ECG

	Acute Kidney Injury	Renal Replacement Therapy	Acute Respiratory Distress Syndrome	Mech Vent	Mortality	Mech Vent or Mortality	ICU, Mech Vent, or Mortality
Overall N (%)	141 (45%)	12 (4%)	51 (16%)	55 (18%)	47 (15%)	64 (20%)	80 (25%)
Odds Ratio	3.3	4.5	7.2	6.4	11.4	7.6	5.2
95% CI	1.5-7.3	1.3-16.0	3.3-15.5	3.0-13.5	5.2-24.9	2.6-16.3	2.5-11.0
P-value	0.001	0.011	0.001	0.001	0.001	0.001	0.001

Outcomes of patients according to right heart strain−electrocardiograms (RHS-ECGs). Patients with RHS-ECGs had a higher incidence of all primary and secondary outcomes (all p values < 0.05). CI = confidence interval; ICU = intensive care unit: Mech Vent = mechanical ventilation.

FIGURE 2 Intubation and Mortality Kaplan-Meier Survival-Curves for Patients According to the Presence of RHS Patterns on 12-Lead ECG
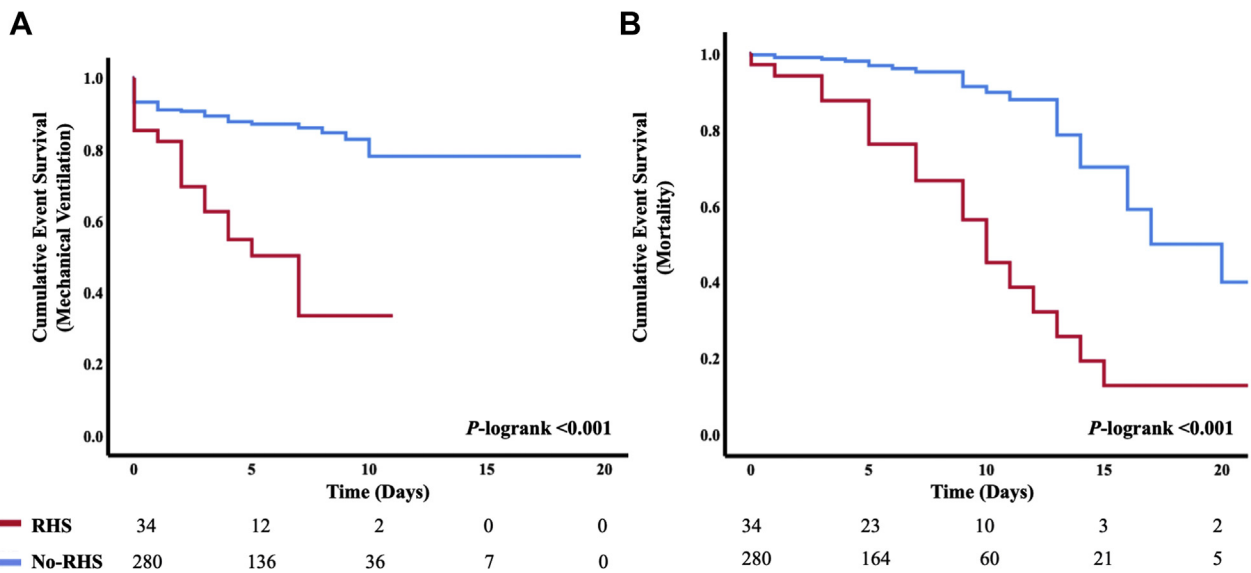
Comparison of **(A)** Mech Vent and **(B)** mortality rates among patients with and without RHS-ECG as obtained in the emergency department. The Kaplan-Meier curves illustrate the powerful and early discriminatory ability of the presence of RHS-ECGs on the risk of **(A)** Mech Vent and **(B)** mortality. Abbreviations as in **Figure 1**.
Abbreviations: New Right Heart Strain Patterns on Presenting 12-Lead Electrocardiogram (RHS-ECG)

(29%) patients had an early R/S transition within the anterior chest leads. **Table 2** lists the different combinations observed.

Only 2 of 40 patients had computed tomography angiograms performed to rule out pulmonary embolism, and one-half of the tests were positive. An echocardiogram was performed on 4 of 40 patients, and RV dysfunction was present in 3 of 4 patients (sample ECG and echocardiogram of a sample patient are shown in Supplemental Figure 1 and Videos 1A and 1B, respectively).

BASELINE CLINICAL AND LABORATORY CHARACTERISTICS OF PATIENTS WITH COVID-19 ACCORDING TO THE PRIMARY OUTCOMES. Mortality and the need for mechanical ventilation in the COVID-19 cohort were 15% and 18%, respectively. The characteristics of the overall population, according to the primary outcomes, are listed in Supplemental Table 1. Patients who were intubated were more likely to be men, and those who were deceased were more likely to be older (Supplemental Table 1). Patients who were intubated or died had a lower SPO_2/FiO_2 ratio in the ED (Supplemental Table 1) and were more likely to have ECG findings suggestive of RHS (Supplemental Table 1). Patients who required mechanical ventilation were more likely to have atrial fibrillation on

ECG. Patients who were intubated or died were more likely to have a higher number of comorbidities, including heart failure, atrial fibrillation, cerebrovascular disease, chronic kidney disease, chronic obstructive pulmonary disease, and be smokers (Supplemental Table 1). They were also more likely to have higher high-sensitivity troponin lactate dehydrogenase, ferritin, and D-dimer levels. There was also no difference in chest imaging findings between the different outcome groups (Supplemental Table 1).

OUTCOMES ACCORDING TO THE PRESENCE OF SIGNS OF RHS ON ECG. Patients with RHS-ECGs were significantly more likely to be intubated, discharged deceased, or their composite, as outlined in the multivariable analysis section in the following (**Figure 1, Table 3, Central Illustration,** Supplemental Table 2). Furthermore, these patients were more likely to develop AKI and ARDS, as well as require renal replacement therapy (**Figure 1,** Supplemental Table 2). There was no statistical difference in the median time to intubation (2 days; interquartile range [IQR]: 0 to 4 days vs. 2 days; IQR: 0 to 3 days; p = 0.199) or mortality (9 days; IQR: 5 to 13 days and 13 days; IQR: 7 to 15.5 days; p = 0.26). The statistical performance of RHS-ECG in relation to our primary outcomes were as follows: mechanical ventilation (sensitivity: 50%; 95%

CENTRAL ILLUSTRATION Incidence and Survival Curves of Primary Outcomes According to the Presence of Right Heart Strain Patterns on Presenting 12-Lead Electrocardiogram
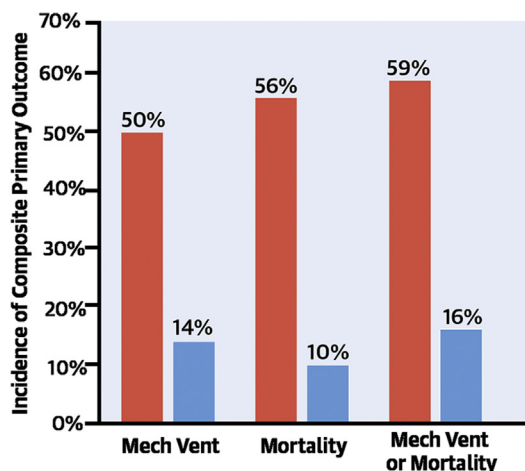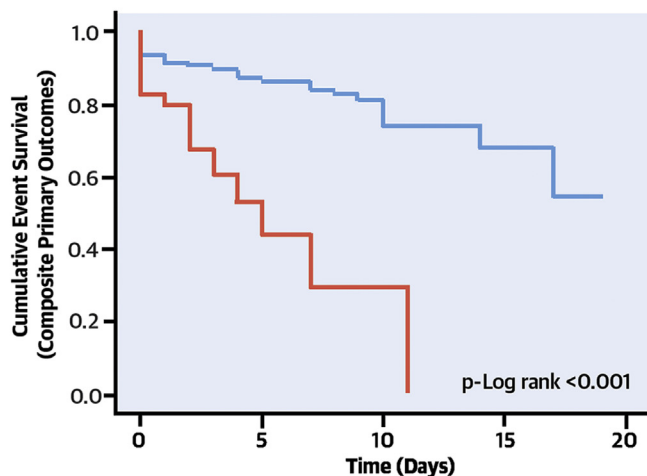
Raad, M. et al. J Am Coll Cardiol EP. 2020;■(■):■-■.

Patients with right heart strain–electrocardiograms (RHS-ECGs) on presentation to the emergency department had a significantly higher incidence of in-patient need for mechanical ventilation (Mech Vent) and/or mortality. The Kaplan-Meier curves illustrate the powerful and early discriminatory ability of the presence of RHS-ECGs for the risk of the composite of mortality and the need for Mech Vent. CI = confidence interval.

confidence interval [CI]: 32% to 68%; specificity: 94%; 95% CI: 90% to 96%); mortality (sensitivity: 40%; 95% CI: 26% to 56%; specificity: 94%; 95% CI: 91% to 97%); and composite of mortality or mechanical ventilation (sensitivity: 31%; 95% CI: 20% to 44%; specificity: 90%; 95% CI: 91% to 97%). The presence of RHS-ECG also provides an early and powerful discriminatory ability for the risk of mechanical ventilation (**Figure 2A**), mortality (**Figure 2B**), and their composite (**Central Illustration**).

MULTIVARIABLE ANALYSIS FOR THE INDEPENDENT PREDICTORS OF INPATIENT NEED FOR MECHANICAL VENTILATION AND MORTALITY. A multivariable regression analysis for intubation and for mortality used clinical variables that were independently associated with each outcome (**Table 2**). Age 65 years or older was used, and cardiac injury was defined as a high-sensitivity troponin level >99th percentile (>18 ng/l, per our assay) (5). Continuous variables were converted to a 20-point scale based on the highest value that our assay would measure (ferritin,

D-dimer, and lactate dehydrogenase) and on the highest ratio obtainable on room air (SPO$_2$ = 100% and FiO$_2$ = 0.21) for SPO$_2$/FiO$_2$. RHS-ECG continued to be independently associated with mortality (adjusted odds ratio [adjOR]: 15.2; 95% CI: 5.1 to 45.2; p < 0.001) (**Table 3**), the need for mechanical ventilation (adjOR: 8.8; 95% CI: 3.4 to 23.2; p < 0.001) (**Table 3**), and their composite (adjOR: 12.1; 95% CI: 4.3 to 33.9; p < 0.001) (**Table 3**).

DISCUSSION

In this study, we described the characteristics and outcomes of patients hospitalized with COVID-19 according to RHS-ECGs on the presenting ECG obtained in the ED. This study revealed that RHS-ECGs were associated with a higher risk of worse outcomes, including mortality, mechanical ventilation, AKI, renal replacement therapy, and ARDS.

Cardiovascular comorbidities were shown to be associated with a higher risk of morbidity and mortality in patients admitted with COVID-19 (11,12).

Several studies also revealed that cardiac injury, as evidenced by elevated troponin, is associated with worse outcomes, including ARDS and mortality (4). The link between the mechanism of cardiac injury associated with COVID-19 and worse outcomes is not well elucidated. In our study, we observed an association between RHS-ECGs and cardiac injury, both of which were independent predictors of worse outcomes in patients admitted with COVID-19.

It is difficult to assess direct causation, especially because these ECG signs suggested RV strain and were mostly not supported by further evaluation. However, a few speculations could be drawn. In our study, 3 of 4 of echocardiograms performed on patients with RHS-ECGs revealed findings consistent with RV dysfunction. Published studies and case series showed that RV dysfunction appears to be the predominant cardiac pathology on the in-patient echocardiograms performed (13). The mechanism of RV dysfunction could be due to multiple factors. Respiratory failure is the most common cause of death in patients admitted with COVID-19. Hypoxic vasoconstriction or physical destruction of the capillary beds that leads to elevated pulmonary vascular resistance is one of the proposed mechanisms of RV dysfunction. RHS-ECGs continued to be an independent predictor of the need for mechanical ventilation or mortality, even after factoring in the degree of hypoxia using the $SPO_2:FiO_2$ ratios. Patients admitted

with COVID-19 also had an increased prevalence of venous thromboembolism (14-16), and autopsies revealed a marked presence of pulmonary microthrombosis (17), which could result in RV strain. Unfortunately, acute pulmonary emboli were not well accounted for, because there were only 2 patients who had a dedicated computed tomographic pulmonary angiography. Adding D-dimer to the

TABLE 2 Patterns of 12-Lead ECG Findings Consistent With RHS-ECG

12-Lead ECG Findings	No. of Patients
RAD	6
$S_1Q_3T_3$	4
RBBB + RAD	4
STD and TWI V_1 to V_4 or II-III-aVF	3
RAD + early R/S transition	3
RBBB + STD and TWI V_1 to V_4 or II-III-aVF	3
RBBB + $S_1Q_3T_3$	2
STD and TWI V_1 to V_4 or II-III-aVF2 + early R/S transition	2
RAD + $S_1Q_3T_3$	2
$S_1Q_3T_3$ + early R/S transition	1
RBBB + $S_1Q_3T_3$ + STD & TWI V_1 to V_4 or II-III-aVF + early R/S transition	1
Incomplete RBBB + $S_1Q_3T_3$ + STD and TWI V_1 to V_4 or II-III-aVF + early R/S transition	1
RAD + $S_1Q_3T_3$ + early R/S transition	1
RAD + $S_1Q_3T_3$ + STD & TWI V_1 to V_4 or II-III-aVF + early R/S transition	1

RAD = right-axis deviation; RBBB = right bundle branch block; STD = ST depressions; TWI = T-wave inversion; other abbreviations as in **Table 1**.

TABLE 3 Predictors of Inpatient Mortality, Need for Mechanical Ventilation, and Their Composite After Multivariable Regression Using Clinical Data Elements From the Emergency Department

Variables	Unadjusted OR (95% CI); p Value	Adjusted OR (95% CI); p Value
Mortality		
RHS-ECG	11.4 (5.2–24.9); <0.001	15.2 (5.1–45.2); <0.001
SPO_2/FiO_2	0.80 (0.74–0.86); <0.001	0.81 (0.74–0.89); <0.001
Cerebrovascular disease	7.7 (2.5–24.3); <0.001	9.0 (1.6–50.7); 0.013
Cardiac injury	6.6 (3.3–13.3); <0.001	3.8 (1.5–9.6); 0.004
Ferritin	1.3 (1.1–1.7); 0.014	1.4. (1.1–1.9); 0.031
Smoking history	3.5 (1.9–6.8); <0.001	3.1 (1.2–7.7); 0.016
Mechanical ventilation		
RHS-ECG	6.4 (3.0–13.5); <0.001	8.8 (3.4–23.2); <0.001
Cerebrovascular disease	6.2 (2.0–19.4); <0.001	5.5 (1.3–21.7); <0.016
SPO_2/FiO_2*	0.78 (0.72–0.84); <0.001	0.80 (0.74–0.87); <0.001
Lactate dehydrogenase*	1.3 (1.2–1.5); <0.001	1.2 (1.1–1.4); 0.013
Composite of mortality or mechanical ventilation		
RHS-ECG	7.7 (3.6–16.3); <0.001	12.1 (4.3–33.9); <0.001
Cerebrovascular disease	7.0 (2.2–22.4); <0.001	7.8 (1.8–33.9); 0.006.
SPO_2/FiO_2*	0.76 (0.71–0.82); <0.001	0.77 (0.70–0.84); <0.001
Lactate dehydrogenase*	1.3 (1.1–1.5); <0.001	1.2 (1.1–1.3); 0.037

Variables controlled for RHS-ECG, age 65 years or older, cardiac injury, atrial fibrillation/ flutter, cerebrovascular disease, chronic kidney disease, chronic obstructive lung disease, smoking history, SPO2/FiO2, lactate dehydrogenase, *ferritin, and *D-dimer. *Continuous variables were converted to a 20-point scale with their maximal laboratory value (per assay) corresponding to 20 points.

CI = confidence interval; OR = odds ratio; other abbreviations as in **Table 1**.

multivariable analysis did not null the effect of the association of RHS-ECGs with mortality or the need for mechanical ventilation.

Respiratory and cardiac complications are life-threatening diagnostic dilemmas in patients with COVID-19 (2,18). Patients with evidence of RHS on initial ECGs had significantly higher rates of mechanical ventilation and mortality, which was not previously reported. Do et al. (19) demonstrated that continuous ECG changes on telemetry consistent with RHS preceded asystole and/or pulseless electrical activity arrest from hypoxic respiratory failure. It was also possible that patients with RHS-ECGs in our cohort represented those who presented later in the course of their COVID-19 illness. This was also further evidence that RV dysfunction was an end-stage complication before adverse events. Among available clinical tools, ECGs are easily performed, cost-effective, and widely available. The detection of RHS-ECGs provided a simple and powerful tool with early discriminatory ability, as early as presentation to the ED. However, only 314 of 480 (65%) patients in our cohort had an ECG obtained in the ED, with even lower rates in a previous published cohort from Wuhan (4). We suggest obtaining a baseline ECG for all patients admitted with COVID-19 because identification of RHS-ECG may guide early triage and management of these patients.

STUDY LIMITATIONS AND FUTURE DIRECTIONS. The main limitation of our study was its retrospective design. Despite controlling for multiple variables, there might be confounding variables for which we did not account. The patient population chosen included those who were admitted, and they could not be generalized to all patients with COVID-19. Furthermore, patients were excluded if they were still admitted at the time of data collection and analysis because our primary outcome could not be accurately assessed. Although ECG findings suggestive of RHS conferred worse outcomes, the data available did not allow correlation with echocardiographic findings, nor did they allow a complete assessment of possible etiologies (e.g., pulmonary emboli). Larger prospective studies will be required to validate and better characterize our results in relationship to echocardiographic evidence of RV strain in addition to potential mechanisms such as pulmonary embolism. The temporality of RHS-ECG patterns could not be ascertained entirely despite being new compared with previous ECGs present. Therefore, these findings might have been present before admission and not related to COVID-19. However, these findings were still beneficial for risk prediction because our results revealed an early discriminatory ability of RHS-ECGs when obtained as early as presentation to the ED. Prospective trials will help address this limitation in addition to any benefit in serial risk prediction with serial in-patient ECG or telemetry monitoring to assess whether the evolution and/or resolution of RHS-ECGs confers different inpatient risks.

CONCLUSIONS

The presence of RHS-ECGs was associated with an increased risk of critical illness in patients admitted with COVID-19. Special attention should be given to patients with COVID-19 with RHS-ECGs.

AUTHOR DISCLOSURES

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: SARS-CoV-2 is a highly contagious and virulent pathogen. In areas of high case density where resource allocation is desperately needed, cost-effective and easily performed tests that can risk stratify patients are invaluable. In our study, the detection of new RHS patterns on the presenting ECG predicted critical illness in patients admitted with COVID-19. This could potentially facilitate early triage and management of patients with COVID-19 presenting to the ED with RV strain. In addition, this finding highlighted the role of RV dysfunction in the pathophysiology of COVID-19.

TRANSLATIONAL OUTLOOK: Validation of our findings in a larger prospective patient population will provide a novel prognostic marker that can be used in prediction models to facilitate appropriate patient triage and resource allocation.

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KEY WORDS COVID-19, ECG, emergency department, right heart strain, right ventricular dysfunction

APPENDIX For supplemental figure and tables, please see the online version of this paper.