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Inpatient cardiac monitoring using a patch-based mobile cardiac telemetry system during the COVID-19 pandemic

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Abstract

Introduction: Coronavirus disease 2019 (COVID-19) is a worldwide pandemic, and cardiovascular complications and arrhythmias in these patients are common. Cardiac monitoring is recommended for at risk patients; however, the availability of telemetry capable hospital beds is limited. We sought to evaluate a patch-based mobile telemetry system for inpatient cardiac monitoring during the pandemic.

Methods: A prospective cohort study was performed of inpatients hospitalized during the pandemic who had mobile telemetry devices placed; patients were studied up until the time of discharge or death. The primary outcome was a composite of management changes based on data obtained from the system and detection of new arrhythmias. Other clinical outcomes and performance characteristics of the mobile telemetry system were studied.

Results: Eighty-two patients underwent mobile telemetry device placement, of which 31 (37.8%) met the primary outcome, which consisted of 24 (29.3%) with new arrhythmias detected and 18 (22.2%) with management changes. Twenty-one patients (25.6%) died during the study, but none from primary arrhythmias. In analyses, age and heart failure were associated with the primary outcome. Monitoring occurred for an average of 5.3 ± 3.4 days, with 432 total patient-days of monitoring performed; of these, QT-interval measurements were feasible in 400 (92.6%).

Conclusion: A mobile telemetry system was successfully implemented for inpatient use during the COVID-19 pandemic and was shown to be useful to inform patient management, detect occult arrhythmias, and monitor the QT-interval. Patients with advanced age and structural heart disease may be more likely to benefit from this system.

KEYWORDS
arrhythmia, cardiac monitoring, COVID-19, mobile telemetry, telemetry

1 | INTRODUCTION

Coronavirus disease 2019 (COVID-19) is a newly recognized infectious disease that is now the cause of a worldwide pandemic, with an escalating number of fatalities attributed to the disease. Cardiovascular complications[1] and arrhythmias are common, especially among patients with myocardial injury.[2] Initial treatment strategies included coadministration of hydroxychloroquine, an antirheumatic and antimalarial drug, and azithromycin, a macrolide antibiotic,[3,4] which are both known to affect the QT interval and

increase risk for arrhythmias including torsade de pointes.[5] At the time of publication these therapies may be falling out of favor.

Given the increased risk of arrhythmias among patients with COVID-19, especially those with baseline QT-interval abnormalities and those being treated with hydroxychloroquine and/or azithromycin, current guidelines recommend monitoring of the QT-interval with serial electrocardiography (ECGs) or telemetry monitoring among these patient groups.[6] Serial ECG monitoring may lead to increased viral exposure to staff, and access to intensive care unit (ICU) and telemetry capable hospital beds is limited in the face of the pandemic.[7] Therefore, alternative methods of monitoring may be useful. Other investigators have shown that mobile cardiac telemetry devices may be useful in this setting.[8–10]

Leadless, patch-based mobile telemetry devices have been shown to have good diagnostic utility in the ambulatory setting.[11,12] Newer devices include mobile telemetry technology for the real-time monitoring of arrhythmias but are typically used in the ambulatory setting. We sought to evaluate the utility of a patch-based mobile cardiac telemetry system for inpatient cardiac monitoring during the COVID-19 pandemic.

2 | MATERIALS AND METHODS

2.1 | Mobile telemetry system design

In response to the COVID-19 pandemic, it was recognized that the conventional critical care and telemetry resources of our institution would be overwhelmed. We therefore developed a system to provide cardiac monitoring to high risk COVID-19 and other inpatients who under conventional conditions would qualify for intensive monitoring, but with the limited resources engendered by the crisis were unable to access them. We created a multi-campus solution enabling inpatient cardiac monitoring using the Zio Patch AT (iRhythm Technologies Inc). This system allowed for telemetry and periodic QT monitoring on hospital floors while limiting staff exposure to high-risk viral conditions. A system of central cardiac monitoring was created to provide daily assessment of cardiac rhythm and QT-intervals supervised by cardiac electrophysiologists, as well as an urgent alert system which provided clinical staff with telemetry data of potentially life-threatening arrhythmias. The Zio Patch system received emergency Food and Drug Administration (FDA) approval for inpatient cardiac monitoring during the COVID-19 pandemic; QT-interval measurement using this system is not currently FDA approved and was done on an experimental basis.

Patients were fitted with the mobile cardiac telemetry device, which includes a 1-lead adhesive patch monitoring device and cellular transmitter, by hospital-employed ECG technicians who had prior experience with the product. Once in place, cardiac telemetry was recorded and analyzed continuously by the monitoring device; based on pre-specified arrhythmia criteria and routinely once per day, 90 s recordings were transferred to the device manufacturer through the use of the cellular transmitter. Transmission were monitored at all times (including nights and weekends) by commercial telemetry technicians, and additionally during business hours by a team of hospital-based cardiologists and electrophysiologists. Telemetry interpretations and QT-interval measurements were provided to clinical teams daily by the cardiology team via the electronic medical record (EMR) or telephone when appropriate. Critical alerts were delivered directly from the commercial telemetry technicians to the clinical team on the hospital floors via telephone.

Critical alerts necessitating urgent notification consisted of episodes of wide QRS tachycardia ≥ 150 beats per minutes (bpm) for ≥15 s, complete heart block six beats or greater, pause ≥6 s, atrial fibrillation or flutter ≥180 bpm or ≤40 bpm for ≥60 s, narrow QRS tachycardia ≥200 bpm for ≥60 s, and ventricular fibrillation.

2.2 | Study design and population

A prospective cohort study of patients undergoing inpatient treatment during the COVID-19 pandemic at three campuses within a large urban academic medical center and who had the patch-based mobile cardiac telemetry device placed was performed. The decision to order the mobile telemetry device was at the discretion of the treating physicians. To be eligible for device placement, patients on non-ICU and non-telemetry capable hospital units and were suggested to meet at least one of the following criteria: Prolonged QT on admission ECG defined as QTc > 470 ms for males or >480 ms for females and considered for treatment with agents which can further prolong the QT interval, history of QT prolongation in the past with pharmacologic therapy, anticipated therapy with two or more agents capable of QT prolongation (e.g., hydroxychloroquine + azithromycin or methadone), high oxygen supplementation requirements (e.g., non-rebreather mask, high-flow nasal cannula, or ventilator support), or history of or concern for arrhythmias.

For patients who underwent mobile telemetry device placement, baseline demographic and clinical data were collected from the Epic EMR system including age, sex, race, or ethnic group, severe acute respiratory syndrome coronavirus 2 test results, oxygen therapy and ventilatory requirement at the time of device placement, antiarrhythmic and other QT prolonging medication use before admission. Medical history was also obtained including history of hypertension, diabetes, heart failure, left ventricular hypertrophy, arrhythmias, chronic kidney disease, and use of renal replacement therapy, as well as presence of cardiac implantable electronic devices. Baseline electrocardiographic data were obtained from ECGs at the time of hospital admission including rhythm, QT-interval and QTc calculated using the Bazett formula, heart rate, and QRS duration; these measurements were performed manually by the study investigators using digital calipers. Left ventricular ejection fraction was recorded from echocardiograms performed most proximate in time to telemetry device placement. Relevant laboratory parameters were recorded most proximate in time to device placement.

Indication for mobile telemetry device placement was assessed and categorized into five groups: hydroxychloroquine use, prolonged

QT, history of or concern for arrhythmias, hypoxia, and use of other QT prolonging agents. Patients could be placed into more than one group.

2.3 | Follow-up and outcomes

Patients were followed up until the time of discharge, death, or completion of the 3-week study period. The primary outcome was a composite of changes in management in response to information from the mobile telemetry system (e.g., cessation of QT-interval prolonging medications due to prolongation of the QT-interval or management of arrhythmias) and detection of new arrhythmias, defined as arrhythmias not previously documented in the patient's medical record. These outcomes were also analyzed individually. Management changes were further delineated into management changes based on QT-interval prolongation and management of arrhythmias. Detection of new arrhythmias was further delineated as type of arrhythmia detected: atrial fibrillation, other atrial arrhythmias, and ventricular arrhythmias including severe bradycardia. Bradycardias and asystole noted at the end of life were not included in this outcome.

Additional study outcomes were incidence of significant prolongation of the QT interval, defined as QTc (calculated using the Bazett formula) ≥500 ms or increase in the QTc ≥ 60 ms from baseline ECG,[13] incidence of atrial fibrillation during hospitalization (which included atrial fibrillation that occurred outside of the monitoring period), myocarditis/myocardial injury or heart failure during admission, and death. We also recorded information on use of hydroxychloroquine, azithromycin, and other QT-interval prolonging medications during hospitalization.

If desired by the treating physicians, patients could be discharged with the mobile telemetry device to continue cardiac monitoring outside of the hospital settings (e.g., at home or rehabilitation centers). Any additional monitoring performed outside of the hospital setting was not used for the purposes of this study.

2.4 | Mobile telemetry recording analysis

Data on cardiac telemetry including incidence of arrhythmias and measurement of intervals were collected from the Zio Suite system, which allows for review of transmitted 1-lead cardiac rhythm strips from the Zio Patch AT monitors. All recordings during the study period were reviewed by the study investigators. QT and RR-intervals were measured on the cardiac rhythm strips manually by the study investigators using digital calipers, and QTc was calculated using the Bazett formula. A tangent method to assess the end of the T-wave was utilized. Industry supplied QT and QTc interval measurements from the Zio Suite system were recorded. The incidence of critical alerts necessitating urgent provider notification, which included severe tachy- and bradyarrhythmias, was also recorded.

2.5 | Additional ECG data

Data on additional 12-lead ECGs obtained during hospitalization were recorded for patients who had ECGs performed during the mobile telemetry monitoring period to compare QT-interval measurements between 12-lead ECGs and mobile telemetry strips. As with baseline ECGs, information on cardiac rhythm, QT-interval and QTc calculated using the Bazett formula, heart rate, and QRS duration was recorded; measurements were again performed manually by the study investigators using digital calipers.

2.6 | Statistical analyses

Using a statistical software package univariate and multivariate analyses were performed. Univariate associations between baseline clinical characteristics and use of QT-prolonging medications during hospitalization with the primary outcome were assessed using Fisher's exact test for categorical variables or Student's *t* test for continuous variables, with the addition of the Cochran–Armitage test for trend for ordinal variables. Using variables found to be associated with the primary outcome in univariate analysis, a multiple logistic regression was performed to assess for independent associations. Univariate associations of selected clinical characteristics with death were also performed using Fisher's exact test or Student's *t* test where appropriate.

Performance of the mobile telemetry system to accurately measure QT-intervals was assessed by comparing QTc measurements from baseline ECGs and baseline mobile telemetry strips that were performed on the same day, and subsequent ECGs during hospitalization with mobile telemetry strips recorded on the same day. Measurements were compared using the paired Student's *t* test, and Pearson correlation coefficients were calculated. The performance of the industry measured QTc was also assessed by comparison to investigator measured QTc intervals from the same strips using the same method.

Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc). For statistical tests, $p \leq .05$ were considered to be statistically significant. The institutional review board at Montefiore Medical Center/Albert Einstein College of Medicine approved this study in April 2020.

3 | RESULTS

3.1 | Patient characteristics

During the 3-week study period, 88 patients underwent mobile telemetry device placement; six patients who had the device placed and were discharged the same or the next day with plan for outpatient mobile telemetry were excluded, as such 82 patients were included in analyses (Table 1). As shown, patients were predominantly male and

TABLE 1 Baseline clinical characteristics—no (%) unless noted

Total patients enrolled	82
Age (mean ± *SD*)	67.2 ± 13.9
Male	47 (57.3)
Race/ethnic group	
White (non-Hispanic)	3 (3.7)
Black/African American	31 (37.8)
Hispanic	34 (41.5)
Other/unknown	14 (17.1)
SARS-CoV-2 positive	73 (89.0)
Indication for mobile telemetry device use	
Hydroxychloroquine use	30 (36.6)
Prolonged QT	17 (20.7)
Arrhythmia	29 (35.4)
Hypoxia	34 (41.5)
Use of other QT prolonging medications	6 (7.3)
Oxygen/ventilatory requirement at time of device placement	
Room air or nasal cannula	52 (63.4)
Non-rebreather mask	12 (14.6)
High-flow nasal cannula	10 (12.2)
Mechanical ventilation	8 (9.8)
Baseline QT prolongation (>470 for M, >480 for F)	21 (25.6)
Baseline QTc (ms, mean ± *SD*)	451 ± 32
Baseline QRS duration (ms, mean ± *SD*)	88 ± 17
Baseline HR (bpm, mean ± *SD*)	94.4 ± 21.2
LVEF by echocardiogram (%, mean ± *SD*)	59 ± 11
Medication use before admission	
Anti-arrhythmics	2 (2.4)
Other QT prolonging agents	18 (22.0)
Medical history	
Hypertension	64 (78.1)
Diabetes	45 (54.9)
Coronary artery disease	19 (23.2)
Heart failure	17 (20.7)
Left ventricular hypertrophy	6 (7.3)
Atrial fibrillation or flutter	13 (15.9)
Ventricular arrhythmias	2 (2.4)
Chronic kidney disease	18 (22.0)
End-stage renal disease on renal replacement therapy	4 (4.9)
Cardiac implantable electronic device	3 (3.7)
Laboratory parameters at time of telemetry device placement	
Serum sodium (mEq/L, mean ± *SD*)	142 ± 8
Serum potassium (mEq/L, mean ± *SD*)	4.5 ± 0.7
Serum corrected calcium (mEq/L, mean ± *SD*)	9.3 ± 1.0
Serum magnesium (mEq/L, mean ± *SD*)	2.3 ± 0.5
Serum creatinine (mg/dl, mean ± *SD*)	2.3 ± 3.6
Troponin-T (g/ml, mean ± *SD*)	0.07 ± 0.24
Creatine kinase (U/L, mean ± *SD*)	518 ± 992
Pro B-type naturietic peptide (pg/ml, mean ± *SD*)	3,347 ± 5,107
D-Dimer (μg/ml, mean ± *SD*)	5.8 ± 6.6
C-reactive protein (mg/dl, mean ± *SD*)	11.6 ± 9.6
Ferritin (ng/ml, mean ± *SD*)	1,316 ± 1,631

Abbreviation: SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

consisted of racial or ethnic minorities. The primary indication for device use was hypoxia followed by hydroxychloroquine use. Patients were primarily on room air or nasal cannula oxygen, but a substantial number required higher levels of oxygen support including mechanical ventilation.

The majority of patients had hypertension and diabetes, while coronary artery disease and heart failure were less common; the mean left ventricular ejection fraction for the group was normal. Chronic kidney disease was also common among the group. Only two patients were on an antiarrhythmic agent (both amiodarone) before admission, and 15 patients were taking medications capable of QT prolongation which primarily consisted of typical and atypical antipsychotics and methadone.

Serum electrolytes were on average within normal ranges among the patients. Troponin-T concentrations were minimally elevated; however, creatine kinase levels were substantially higher. Pro-B-type natriuretic peptide levels were elevated on average, as well as inflammatory markers including C-reactive protein, D-dimer, and ferritin.

3.2 | Study outcomes

During the study period, 31 patients met the primary outcome, a composite of management changes based on information from the telemetry system and detection of new arrhythmias (Table 2). There was a close to equal balance of the two components, with several patients meeting both criteria. Of new arrhythmias detected, atrial fibrillation was the most common. Two patients developed SVT requiring intervention, and eight patients had ventricular arrhythmias which consisted predominantly of non-sustained monomorphic ventricular tachycardia. One patient had non-sustained polymorphic, torsades appearing ventricular tachycardia; however, QT-interval measurements taken earlier in the day and just before the episode were normal. This patient was found to have significant metabolic abnormalities at the time. He subsequently expired several days later from respiratory failure after comfort measures were instituted. Another patient, who had a history of an ischemic cardiomyopathy, had sustained monomorphic ventricular tachycardia leading to cardiac arrest but was successfully resuscitated. No patients had arrhythmias diagnosed by methods other than the mobile telemetry device while the device was in place.

QT prolongation was relatively common, occurring in 27 patients (32.9%); however, as noted above no instances of torsades de

TABLE 2 Patients meeting study outcomes

Outcome	Patients meeting outcome no. (%)
Primary outcome—composite of management changes and new arrhythmias detected	31 (37.8)
Management changes	18 (22.2)
Management of arrhythmias	11 (13.4)
New oral anticoagulant treatment	5 (6.1)
New antiarrhythmic medication treatment	4 (4.9)
Management of QT-interval prolonging medications	8 (9.8)
New arrhythmias detected	24 (29.3)
Atrial fibrillation	14 (17.1)
Other atrial arrhythmias	2 (2.4)
Ventricular arrhythmias	8 (9.8)
Significant QT Prolongation during admission (QTc > 500 ms or Δ > 60 ms)	27 (32.9)
Atrial fibrillation during admission	23 (28.4)
Myocardial injury during admission	2 (2.5)
Heart failure during admission	4 (4.9)
Death	21 (25.6)

pointes were seen. Atrial fibrillation was also common, while myocardial injury and heart failure were not. Sixty-six patients (80.5%) received hydroxychloroquine during hospitalization, 15 (18.3%) received azithromycin during hospitalization, and 30 (36.6%) received other QT-interval prolonging medications during hospitalizations. Thirty-four (41.5%) received two or more QT-interval prolonging medications.

Death occurred in 21 patients during the study period; in all cases these were adjudicated to be hypoxia or hemodynamically mediated arrests rather than primarily arrhythmic events. Mobile telemetry data was available for 11 of the 21 patients, all demonstrating bradycardia as the inciting terminal event. The remaining patients had either been moved to higher levels of care (telemetry floor or ICU) or had comfort measures instituted and had the device removed before death. In univariate analysis, QT-interval prolonging medication use (including hydroxychloroquine, azithromycin, other QT prolonging medications, and use of two or more QT prolonging medications) was not found to be associated with death ($p = .750$, 1.00, 1.00, and .610 respectively). Significant prolongation of the QT-interval was also not seen to be significantly associated with death ($p = .113$).

Among 73 patients who received any QT-interval prolonging medication during hospitalization, 25 (34.3%) had significant prolongation of the QT-interval. In this group, baseline QTc was 453 ± 31 ms, and peak QTc was 473 ± 44 ms.

3.3 | Univariate and multivariate analysis for the primary outcome

In univariate analysis using baseline clinical and other characteristics, only patient age and history of heart failure were found to be significantly associated with the primary outcome. (Table 3) These associations remained independent in multiple logistic regression for the primary outcome by age and history of heart failure (Table 4).

3.4 | Performance of the mobile telemetry system

During the study period, patients were monitored for an average of 5.3 ± 3.4 days, with monitoring periods ranging from 1 to 14 days. There were 432 total patient-days of mobile telemetry monitoring; of those the QT-interval was able to be measured in 400, 92.6% of the time (Figure 1, Panel A). In cases where the QT-interval could not be measured, the most common reasons were low T-wave amplitude on one-lead telemetry making the clinician's ability to discern the termination of the T-wave difficult, poor baseline of the telemetry strip, and rapid arrhythmias (mainly atrial fibrillation).

Of the 432 total patient-days, both study investigator-measured and industry technologist-measured QT-interval measurements were present in 392. In these cases, there was a mean difference in the QTc measurement of 25.7 ± 35.2 ms ($p < .0001$, Pearson correlation coefficient 0.586), with lower average values reported by the industry technologists (Figure S1). There were 24 patient-days where both mobile telemetry strips and 12-lead ECGs were performed on the same day. Among these, there was no significant difference between study investigator-measured QT-intervals on the 12-lead ECG and mobile telemetry strips with mean difference 3.3 ± 47.2 ms ($p = .737$, Pearson correlation coefficient 0.897), though given the small number of concurrent measurements this may be underpowered to assess for differences (Figure S2).

There were 72 patient-days of monitoring in 25 patients where monitoring occurred on the same day as hydroxychloroquine administration. Assuming daily ECG use for patients receiving hydroxychloroquine without the ability to otherwise monitor the QT-interval, 10 min to obtain a 12-lead ECG, and 5 min to place the mobile telemetry device, this system saved up to 595 min of staff viral exposure time.

Critical notifications occurred in 14 patients. Findings included rapidly conducted atrial fibrillation >170 bpm (Figure 1, Panel B), atrial flutter with slow ventricular rates (pauses >6 s) and sustained monomorphic ventricular tachycardia leading to cardiac arrest with successful resuscitation as noted above. The remaining 11 patients had severe bradycardia or agonal rhythm near the end of life. In all cases except the slow atrial flutter which did not require intervention, the critical notifications were delivered to the hospital staff after changes in patient condition were recognized by the clinical care team and the notification did not change patient management.

TABLE 3 Univariate analysis of clinical characteristics using the primary composite outcome of management changes based on mobile telemetry information and new arrhythmias detected—no (%) unless noted

Characteristic	Met primary outcome ($n = 31$)	Did not meet primary outcome ($n = 51$)	p Value (Fisher's exact or Student's t test)
Age (mean ± *SD*)	74.1 ± 10.4	62.9 ± 14.1	**$p = .0003$**
Sex (male no reported)	17 (54.8)	30 (58.8)	$p = .819$
Race or ethnic group			$p = .316$
White (non-Hispanic)	2 (6.5)	1 (2.0)	
Black/African American	14 (45.2)	17 (33.3)	
Hispanic	12 (38.7)	22 (43.1)	
Other/unknown	3 (9.7)	11 (21.6)	
SARS-CoV-2 positive	27 (87.1)	46 (90.2)	$p = .724$
Indication for mobile telemetry device use			
Hydroxychloroquine use	15 (48.4)	15 (29.4)	$p = .101$
Prolonged QT	6 (19.4)	11 (21.6)	$p = 1.00$
Arrhythmia	13 (41.9)	16 (31.4)	$p = .351$
Hypoxia	14 (45.2)	20 (39.2)	$p = .648$
Use of other QT prolonging medications	3 (9.7)	3 (5.9)	$p = .391$
Oxygen/ventilatory requirement at time of device placement			$p = .477$ (Fisher's), $p = .854$ (Cochran–Armitage)
Room air or nasal cannula	19 (61.3)	33 (64.7)	
Non-rebreather mask	6 (19.4)	6 (11.8)	
High-flow nasal cannula	2 (6.5)	8 (15.7)	
Mechanical ventilation	4 (12.9)	4 (7.8)	
Baseline QTc (ms, mean ± *SD*)	452 ± 37	450 ± 29	$p = .734$
Use of hydroxychloroquine during hospitalization	24 (77.4)	42 (82.4)	$p = .581$
Use of other QT prolonging medications during hospitalization	11 (35.5)	19 (37.3)	$p = 1.00$
LVEF by echocardiogram (%, mean ± *SD*)	57 ± 13	60 ± 8	$p = .287$
Medical History			
Hypertension	26 (83.9)	38 (74.5)	$p = .414$
Diabetes	18 (58.1)	27 (52.9)	$p = .819$
Coronary artery disease	10 (32.3)	9 (17.7)	$p = .178$
Heart failure	11 (35.5)	6 (11.8)	**$p = .022$**
Left ventricular hypertrophy	4 (12.9)	2 (3.9)	$p = .193$
Atrial fibrillation or flutter	8 (25.8)	5 (9.8)	$p = .067$
Chronic kidney disease	9 (29.0)	9 (17.7)	$p = .276$
End-stage renal disease on renal replacement therapy	1 (3.2)	3 (5.9)	$p = 1.00$
Cardiac implantable electronic device	0 (0)	3 (5.9)	$p = .286$
Laboratory parameters at time of telemetry device placement			
Serum sodium (mEq/L, mean ± *SD*)	141 ± 7	142 ± 9	$p = .578$
Serum potassium (mEq/L, mean ± *SD*)	4.5 ± 0.6	4.6 ± 0.7	$p = .462$
Serum corrected calcium (mEq/L, mean ± *SD*)	9.3 ± 1.2	9.2 ± 0.8	$p = .828$
Serum magnesium (mEq/L, mean ± *SD*)	2.2 ± 0.4	2.4 ± 0.6	$p = .178$
Serum creatinine (mg/dl, mean ± *SD*)	2.4 ± 4.1	2.2 ± 3.3	$p = .853$
Troponin-T (ng/ml, mean ± *SD*)	0.11 ± 0.38	0.05 ± 0.07	$p = .238$
Creatine kinase (U/L, mean ± *SD*)	335 ± 222	633 ± 1,237	$p = .207$
Pro B-type naturietic peptide (pg/mL, mean ± *SD*)	4,098 ± 5,572	2,833 ± 4,772	$p = .334$
D-Dimer (μg/ml, mean ± *SD*)	5.0 ± 5.9	6.2 ± 7.0	$p = .447$
C-reactive protein (mg/dl, mean ± *SD*)	11.8 ± 8.2	11.4 ± 10.5	$p = .858$
Ferritin (ng/ml, mean ± *SD*)	1,004 ± 976	1,508 ± 1,913	$p = .193$

Abbreviation: SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

TABLE 4 Multiple logistic regression results for primary outcome

Characteristic	OR	95% CI	*p* Value
Age (OR for 10-year change in age)	2.00	1.31–3.05	$p = .001$
History of heart failure	4.12	1.20–14.18	$p = .025$

Abbreviations: CI, confidence interval; OR, odds ratio.

4 | DISCUSSION

In this study we describe the innovative use of a patch-based mobile cardiac telemetry system in hospitalized patients during the COVID-19 pandemic. This system substantially increased the monitoring capabilities available for high-risk patients with COVID-19 as well as other patients requiring telemetry monitoring. This collaboration between Montefiore Medical Center and our industry colleagues was distinctive and can be a model for future endeavors for the benefit of patients and staff alike.

The study population was primarily patients hospitalized for treatment of respiratory failure due to COVID-19. Many patients required high levels of supplemental oxygen including some requiring mechanical ventilation. Most patients had multiple comorbidities, and average levels of inflammatory markers were high; all these indicating a severely ill patient population.

The primary endpoint of the study, a composite of management changes based on information obtained from the telemetry system and detection of new arrhythmias, was chosen to best represent patients benefitting from placement of the telemetry device. Death was not included in this endpoint; all deaths observed were due hypoxia or hemodynamic compromise and not primarily arrhythmic, so these patients ultimately did not derive additional benefit from cardiac monitoring.

In univariate analysis, only age and history of heart failure were found to be associated with the primary outcome. This outcome was driven heavily by detection of arrhythmias, especially atrial fibrillation, and changes in management based on these arrhythmias. Atrial fibrillation was common in the cohort, occurring in almost 30% of patients, and more than half of the atrial fibrillation was newly diagnosed by the mobile telemetry system. Our study confirms that advanced age and history of heart failure are risk factors for such events.

Ventricular arrhythmias were uncommon, the majority of which were non-sustained monomorphic ventricular tachycardias, a common arrhythmia in critically ill patients.[14] Despite frequent usage of hydroxychloroquine and other QT-prolonging medications, no instances of torsades de pointes were seen, and no patients died from primary arrhythmic causes. This may have been the result of meticulous monitoring by the cardiology team facilitating discontinuation of QT-prolonging medications after QT-interval prolongation was documented and reported to the clinical staff.

Death during hospitalization during the study period was unfortunately common, and we observed that the terminal mode of death in all patient who had the mobile telemetry devices in place at the time of death was bradycardia or asystole followed by agonal rhythm or ventricular fibrillation, suggesting a hypoxia or hemodynamically mediated etiology. No patients were successfully resuscitated after such an event, suggesting the futility of cardiopulmonary resuscitation attempts in these severely ill patients. We found a low rate of life-threatening arrhythmias among a traditionally high-risk population; the absence of malignant ventricular arrhythmias is notable and in contradistinction to the known high risk of mortality in these patients again suggesting non-arrhythmic causes of death such as respiratory failure or thrombotic events.

Use of a mobile cardiac telemetry system for inpatient monitoring during the COVID-19 pandemic has previously been reported by one group, mainly focusing on the ability of the system to monitor the QT-interval during administration of QT-interval affecting medications,[8–10] the use of which may be falling out of favor for the treatment of COVID-19. In the present

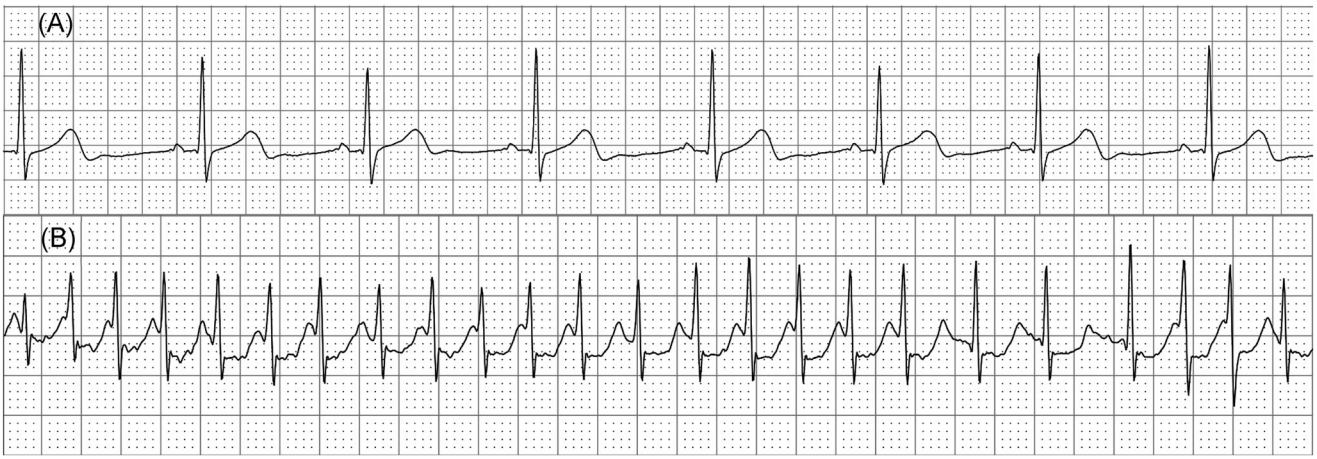

FIGURE 1 Sample one-lead telemetry recordings. (A), A scheduled daily transmission used for the measurement of the QT-interval and (B) a triggered recording alerting the clinical team of rapidly conducted atrial fibrillation

study we report use of a different mobile cardiac telemetry system (Zio Patch system vs. BioTel MCOT system), which provides 1-lead as opposed to 2-lead telemetry. In the present study we report comparison of mobile telemetry derived QT-interval measurements to 12-lead ECG derived measurements, which has not been previously reported. In addition we show the ability of the system to provide information on not only the QT-interval, but also to detect occult arrhythmias and inform management changes. Our study setting, a large urban academic medical center, which serves a high-risk, medically underserved, and racially diverse population is also unique.

For our system, we developed a stringent criterion of critical alerts which were limited to only severe tachy- and bradyarrhythmias due to concerns over staff alert fatigue. We found that the incidence of these alerts was low, and that no false positive alerts were issued. The system was designed such that critical alerts were delivered directly from the commercial telemetry technicians to the hospital unit, however in all cases, patient treatment was already underway at the time an alert was received. This was likely due to the rapid recognition of clinical status changes on the part of the medical care team. To facilitate even more timely alerts, it may be appropriate for notifications to be delivered to the hospital rapid response or code team rather than the hospital floor, especially if the system were to be used in a patient population where the incidence of ventricular arrhythmias requiring acute intervention was expected to be greater. Given the nature of the critical alerts in our patient population, we did not see evidence that these alerts affected patient outcomes.

This study demonstrates the feasibility of utilizing a patch-based mobile telemetry system for inpatient monitoring during a pandemic situation, but this type of system also could be applied during non-pandemic circumstances for selected patients who require cardiac monitoring but are not at excess risk of life-threatening arrhythmias when traditional telemetry resources are insufficient; for example in patients with low-risk acutely decompensated heart failure or syncope, or in settings with limited telemetry hardware resources or local rhythm monitoring expertize. This system can provide the additional benefit of allowing a seamless transition to outpatient cardiac monitoring at the time of discharge. This has the potential to streamline hospital operations providing benefit to patients, providers, and hospital systems.

5 | LIMITATIONS

The primary limitation of this study is its population; no randomization or control group was used, and all patients included in analysis had monitoring devices placed so we are not able to compare patients who were monitored to those who were not. Selection of patients who underwent device placement was at the discretion of the treating physicians, so while higher risk patients on the medical floor are likely to be represented in this study, the highest risk patients are likely to have been monitored in the telemetry or intensive care units rather than the medical floor.

6 | CONCLUSIONS

We developed a system for use during the COVID-19 pandemic for cardiac monitoring of inpatients in non-ICU and non-telemetry units using a patch-based mobile cardiac telemetry device. The system was shown to have utility for informing patient management and detecting occult arrhythmias in a group of patients primarily being treated for COVID-19. The system performed well for detection of arrhythmias, and for the measurement of the QT-interval.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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