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Evaluation of Premature Ventricular Complex during In-Hospital ECG Monitoring As a Predictor of Ventricular Tachycardia in an Intensive Care Unit Cohort

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Abstract

In-hospital electrocardiographic (ECG) monitors are typically configured to alarm for premature ventricular complexes (PVCs) due to the potential association of PVCs with ventricular

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tachycardia (VT). However, no contemporary hospital-based studies have examined the association of PVCs with VT. Hence, the benefit of PVC monitoring in hospitalized patients is largely unknown. This secondary analysis used a large PVC alarm dataset to determine whether PVCs identified during continuous ECG monitoring were associated with VT, in-hospital cardiac arrest (IHCA), and/or death in a cohort of adult intensive care unit patients. Six PVC types were examined (i.e., isolated, bigeminy, trigeminy, couplets, R-on-T, and run PVCs) and were compared between patients with and without VT, IHCA and/or death. Of 445 patients, 48 (10.8%) had VT; 11 (2.5%) had IHCA; and 49 (11%) died. Isolated and run PVC counts were higher in the VT group (p=0.03 both), but group differences were not seen for the other four PVC types. The regression models showed no significant associations between any of the six PVC types and VT or death, although confidence intervals were wide. Due to a small number of cases, we were unable to test for associations between PVCs and IHCA. Our findings suggest that we should question the clinical relevance of activating PVC alarms as a forewarning of VT, and more work should be done with larger sample sizes. A more precise characterization of clinically relevant PVCs that might be associated with VT is warranted.

Keywords

alarm fatigue; in-hospital electrocardiographic monitoring; intensive care unit; premature ventricular complex; ventricular tachycardia

INTRODUCTION

Seminal early research conducted in the 1960s in patients with acute myocardial infarction (MI) showed that premature ventricular complexes (PVCs) often preceded lethal arrhythmias (i.e., ventricular tachycardia [VT] and ventricular fibrillation [VF]) (Lown et al., 1967; Meltzer & Kitchell, 1966). Subsequent studies in MI patients followed for six months also found that PVCs were associated with arrhythmic death (Moss et al., 1977; Ruberman et al., 1977). Based on these studies, suppression of PVCs with antiarrhythmics became a common practice (Vlay, 1985). During this same time, recommendations were published promoting the addition of PVC algorithms into hospital-based electrocardiographic (ECG) monitoring devices (Meltzer & Kitchell, 1966), which eventually occurred and remains in place today for all patients and not only those with MI. Interestingly, in 1989, the Cardiac Arrhythmia Suppression Trial (CAST) showed that patients treated with antiarrhythmics (i.e., encainide and flecainide) had a higher rate of death as compared to patients treated with a placebo (The CAST Investigators, 1988), which altered the practice of suppressing PVCs in hospitalized patients. Hence, while PVC algorithms were introduced into bedside ECG monitor systems, aggressive PVC suppression was no longer standard practice and remains true today. However, no contemporary hospital-based studies have examined the association of PVCs to VT and/or VF. The small number of studies that have been published are dated, included small numbers of patients, and have focused primarily on patients with QT prolongation (Kay et al., 1983; Noda et al., 2004) or idiopathic VF (Noda et al., 2005; Viskin et al., 1997). Thus, contemporary research is needed to examine the association of PVCs with lethal arrhythmias.

Current Practice Standards for ECG Monitoring in Hospital Settings recommend that because PVCs are not considered immediately life-threatening, and in the absence of other indications (e.g., acute coronary syndrome, major cardiac intervention), ECG monitoring for PVCs may be “considered” but is not required (i.e., Class IIb, Level of Evidence C) (Sandau et al., 2017). Despite this recommendation, PVC alarms are commonly activated (audible or inaudible) in bedside and telemetry unit ECG devices with the goal of identifying patients at risk for developing VT and/or VF. Most contemporary ECG monitors now include algorithms that detect a variety of PVC types (e.g., isolated, bigeminy, trigeminy, and R-on-T) designed to add more precision. However, PVCs have been shown to be the most common type of arrhythmia alarm during continuous hospital-based ECG monitoring. In a comprehensive alarm study in 461 consecutive intensive care unit (ICU) patients (77 beds), there were a total of 854,901 PVC alarms during the one-month study period, or 358 PVC/bed/day (Drew et al., 2014). This study was the first to illustrate the sheer number of PVC alarms that nurses and providers are exposed to and likely contribute to the alarm burden. However, this study did not quantify the varied PVC types or examine their association with VT, a common rationale for activating these alarms. While the clinical management of PVCs has changed, largely based on the dated CAST Study, to our knowledge, there has not been a comprehensive evaluation examining the significance of PVCs during hospital-based ECG monitoring. Therefore, this study was designed to (1) determine whether any of six PVC types (isolated PVC, bigeminy, trigeminy, couplet, R-on-T, and run PVC) were associated with the occurrence of VT; and (2) explore whether any of the six PVC types were associated with in-hospital cardiac arrest (IHCA) and/or in-hospital death.

METHODS

Study Design, Sample, and Setting

This study was a secondary analysis of data from an alarm study, details of which have been previously published [Drew et al., 2014]. Briefly, the ICU Alarm Study was designed to determine the number and type of all ECG and physiologic monitor alarms (audible and inaudible) in a consecutive sample of adult ICU patients during one month at a quaternary academic medical center. While 461 patients were available in the primary study, 16 (3.47%) were excluded: one patient with VT storm and 15 had incomplete alarm data. Therefore, 445 patients were included in the present study.

Three adult ICUs were included: cardiac (16 beds), medical-surgical (32 beds), and neurological/neurosurgery (29 beds). Each bed was equipped with a Solar 8000i monitor (version 5.4 software, GE Healthcare, Milwaukee, WI). A specially designed CARESCAPE Gateway system (GE Healthcare, Milwaukee, WI) was used to capture all available physiologic data from each bedside monitor (e.g., seven ECG channels [including PVC alarms], waveform, and numeric vital signs). Data capture occurred in the background; therefore, data collection did not interfere with patient care, nor was it available for clinical decision-making. The university’s institutional review board (IRB) approved both the primary and current study with a waiver of patient consent because of the observational

nature of the study. The data capture system allowed data collection in consecutive ICU patients admitted during March 2013.

Electrocardiographic Data and VT Events

The bedside ECG monitors recorded seven ECG leads: I, II, III, aVR, aVL, aVF, and a V lead (V_1 at our hospital). Six PVC types (specific to the vendor's algorithms) were examined: (1) isolated PVCs (single PVC), (2) bigeminy (PVC alternates with a non-ventricular beat for ≥3 cycles), (3) trigeminy (PVC alternates with 2 non-ventricular beats for ≥3 cycles), (4) couplets (two consecutive PVCs >100 beats/minute), (5) R-on-T (PVC lands on the ST or T wave portion of the previous beat), and (6) run PVCs (3 to 5 consecutive ventricular beats ≥100 beats/minute).

True VT was identified by human annotation conducted by four Ph.D. prepared nurse-scientists using a standardized protocol [Drew et al., 2014]. All of the annotators were ECG experts, had extensive clinical ICU experience, and were skilled users of bedside ECG and physiologic monitors. There was 95% agreement among the annotators (Cohen's Kappa score of 0.86). VT was annotated as true if the event met the following criteria: ≥6 consecutive wide QRSs (ventricular beats) with a heart rate ≥100 beats/minute; simultaneous drop in arterial or pulmonary artery pressure; documentation of the VT event in the electronic health record (EHR); atrioventricular (AV) dissociation present throughout the wide QRS tachycardia in any of the seven ECG leads; and in patients with bundle branch block (right or left) the QRS morphology during the VT differed from the patient's baseline rhythm.

Patient and Clinical Data

Demographic and clinical characteristics were collected from the EHR (Epic Systems Corporation, Verona, WI). Demographic data collected included age, sex, and race. The following cardiovascular history was collected: ischemic heart disease (IHD), heart failure (HF), percutaneous coronary intervention (PCI), and/or coronary artery bypass graft (CABG) surgery. Left ventricular ejection fraction (LVEF) determined from an echocardiogram during the current hospitalization was obtained. If an echocardiogram was not available for the current admission, an LVEF documented within six months prior to ICU admission was used. Both the LVEF percentage (%) and the categorical evaluation (i.e., non-reduced LVEF ≥41% and reduced LVEF ≤40%) were obtained. All standard 12-lead ECGs (over-read by a board-certified cardiologist) that were obtained within the first 24-hours of ICU admission were used to determine the presence of baseline PVCs. The following categories were used for ICU diagnosis: cardiovascular, medical-surgical, and neurological-neurosurgical diagnoses. Medications that could potentially prevent an arrhythmia (antiarrhythmic), provoke an arrhythmia (proarrhythmic), or have both properties (pro-antiarrhythmic) were collected (Al-Khatib et al., 2018; Woosley RL et al., n.d.). Magnesium and potassium replacement therapy was also collected.

Group Comparisons for Patients with and without VT

Patients were placed into two groups based on the presence or absence of VT using the following approach. In the group with VT, PVCs that occurred 24-hours prior to the first

VT event were examined. A time period of 24-hours prior to VT was selected because this method has been used in studies examining ECG changes prior to IHCA (Do et al., 2015; Do et al., 2019). For comparison, a 24-hour period with a peak count of PVCs was used in the non-VT group. This methodological approach was used with the assumption that frequent PVCs would make a patient more at risk for VT; thus, it would be a reasonable comparator group. The administration of medications and electrolyte replacement therapy (described above) during the selected 24-hour period in both groups was examined.

Statistical Analysis

Descriptive statistics: Frequencies, means, and standard deviations were calculated to describe demographics, clinical characteristics, medications, and ICU diagnosis. Means, medians, and interquartile ranges were calculated to describe the six PVC types and their distributions. Differences in variables between VT and non-VT groups were computed using a t-test (for continuous) and chi-square (for categorical). Differences in the PVC distribution between the two patient groups were compared using the Kruskal-Wallis test.

Association of PVCs and VT: We conducted logistic regression, with PVCs being significant if they met a Bonferroni correction for the six PVCs of $p<0.0083$ (i.e., 0.05/6). Since the PVC count data were highly skewed, we grouped patients using quartiles or tertiles (to prevent cell counts from being too small) with zero inflation (depending on the distribution) for each PVC type. These PVC categories were then used as covariates in the logistic model (described below).

We first examined the association between each of the PVC covariates and the occurrence of VT using univariate logistic regression. We then sought to adjust these results for potential confounders (i.e., demographics, clinical history, and ICU clinical factors) in a multiple logistic regression model fitting a separate multivariable logistic regression for each PVC covariate of interest. Although we identified a number of potential confounders from previous work, other previous work has suggested that logistic regression can fit approximately p/10 covariates in the model (with p representing the number of variables in the model) (Harrell et al., 1996; Steyerberg et al., 2000), although recent work has suggested this threshold may be too conservative (Hosmer et al., 2013; Vittinghoff & McCulloch, 2007). As such, for each PVC covariate of interest, we first forced the PVC covariate of interest into the model. Then, due to large amounts of missing data in two potentially important confounders, we followed a multiple imputation approach described in van Buuren (van Buuren, 2018; Vergouwe et al., 2010; Wood et al., 2008) to include additional potential confounders, where we: (1) fit 50 multiple imputations (using mice v3.8.0 [Van Buuren & Groothuis-Oudshoorn, 2011]); (2) used a majority rule to for an initial selection of covariates, keeping those selected by Akaike information criterion (AIC) in half of the models; and (3) used backward selection based on a Wald test method to prune this selection until a final model was reached. We note that there was missing data in only two covariates, 61.3% of LVEF measurements were missing and 21.3% presence of PVC on 12-lead ECG were missing; recent work has suggested even large amounts of missing data can be better modeled via multiple imputation (Lee & Huber, 2021). To assess how well the imputation worked, we looked at the imputation distributions of these covariates, which

were similar to the data itself (e.g., the former had a proportion of 17.0% in the observed non-missing data, and an interquartile range of 15.8%−18.7% among the imputed datasets, and the latter had proportion 7.2% in the observed data, and IQR 6.6%−7.4% in the imputed data). We also note that neither was generally brought into the multivariable models; only two of the multivariable model fit included LVEF, and none included presence of PVC. In addition, as a sensitivity analysis, we also ran these regressions without these two variables to ensure the results were similar. Additionally, potential confounders and PVC covariates of interest were first tested for correlation (all had pairwise r^2<0.2, except for CABG and IHD with r^2=0.432; neither of which made it into the multivariable model when allowing one or the other) to avoid potential issues of multicollinearity.

Association of PVCs to IHCA or Death: We conducted an exploratory analysis to test for any associations between PVC covariates and IHCA or in-hospital death, using a similar approach described above. All analysis was performed using R *v4.0.0* (R Core Team, 2020).

RESULTS

The mean age of the sample (n=445) was 60 ± 17 years, 54.6% were male (n=243), and the majority were white (n=269, 60.4%). Most of the patients were admitted with a medical-surgical diagnosis (n=178, 40%), followed by neurological/neurosurgical diagnosis (n=170, 38.2%), then cardiac diagnosis (n=97, 21.8%). There were 24 patients (6.9%) who had a PVC(s) present on a standard 12-lead ECG at ICU admission, and 31 (18.0%) had a reduced LVEF (see Table 1 for more details). A history of IHD was present in 71 patients (16.0%), PCI/CABG in 38 (8.5%), and HF in 44 (9.9%). Of the 445 patients, 11 (2.5%) had an IHCA event and 49 (11.0%) died. A higher proportion of patients with VT had a cardiovascular diagnosis (p<0.001), reduced LVEF (p<0.001), history of IHD (p=0.002), PCI/CABG (p=0.001), or HF (p<0.001). Patients with VT were more likely to have IHCA (14.6% vs. 1.0%; p<0.001) than non-VT patients. While a higher proportion of the VT group died, there was no statistical difference between the two groups (18.8% vs. 10.1%; p=0.07).

Isolated PVCs were the most common type for both groups, and R-on-T type PVCs were the least common. Except for isolated PVCs (mean 448 ± 1125 vs. 570 ± 996, p=0.031) and run PVCs (7 ± 60 vs. 16 ± 53, p=0.032), there were no differences between the two groups (non-VT vs. VT) for the remaining four PVC types (Table 2).

Because the PVC counts for the six PVC types were highly skewed, patients were grouped for each PVC type (depending on the distribution) into quartiles (isolated PVC, couplets, and run PVC), or tertiles with zero inflation (bigeminy, R-on-T, and trigeminy) (see Table 3). In both unadjusted and adjusted logistic regression models, none of the six PVC types were associated with VT (Table 4), although they had very wide confidence intervals. For the adjusted results, we fit a separate multiple imputation stepwise model for each PVC type after forcing it into the model (see Methods): cardiovascular primary diagnosis, drugs with both pro- and antiarrhythmic properties, and history of heart failure were brought into all models (Suppl. Table A). We found similar results in the sensitivity analysis (Suppl. Table B).

Exploratory Analysis: Association of PVCs to IHCA and/or Death

Because of the small number of IHCA cases (2.5%), we were especially underpowered to detect whether any of the six PVC types were associated with IHCA. Regarding death, 49 (11.0%) died, but there was no difference by group (40 [10.1%] no VT vs. 9 [18.8%] VT group; p=0.07) (Table 1). For PVC counts, the unadjusted isolated PVC count (p<0.005) was significant; however, after adjusting for confounders (see Methods), it no longer met a Bonferroni level of significance (p=0.043). We again noted that the estimates had very wide confidence intervals (Suppl. Table C). Results were similar in the sensitivity analysis (Suppl. Table D).

DISCUSSION

To our knowledge, this is the first contemporary hospital-based ECG study that included 445 consecutive ICU patients examining the association of six different PVC types and the occurrence of VT. After controlling for potential confounders, none of the six PVC types were associated with VT, which supports the current American Heart Association (AHA) Practice Standards for ECG Monitoring in Hospital Settings concerning PVC monitoring (Sandau et al., 2017).

A prior study showed that PVCs were the most frequent arrhythmia alarm, with an astounding 854,901 total PVC alarms in one month among 461 ICU patients (Drew et al., 2014). However, this study only reported the total number of PVCs and did not differentiate the PVC types. In addition, the association between PVCs and VT was not examined. Our data show that PVCs during continuous ECG monitoring did not show a strong effect in relation to the occurrence of VT and, therefore, might increase the risk for alarm fatigue in nurses due to excessive PVC counts. While one could argue that PVC alarms—typically configured as inaudible text message alerts—do not increase alarm fatigue, the flashing message on the bedside monitor draws the nurses' attention to the monitor, causing them to wonder if there is a problem with the patient that needs addressing (Simpson & Lyndon, 2019), which may negatively impact workflow. It is important to acknowledge that some hospitals use monitor watchers/technicians to screen for alarms, which may reduce the alarm burden on nurses. However, the alarm burden is simply shifted from the nurse to the monitor watcher/technician, who may still decide to alert the nurse depending upon the notification protocol used by the hospital. Regardless of who is exposed to the alarms (monitor watcher/technician or nurses), the alarms potentially distract them from patient care. A more meaningful PVC alarm might be one that identifies new-onset PVCs, which might signal an acute physiologic change (e.g., electrolyte imbalance or myocardial ischemia) in a patient that warrants closer assessment. In addition, trended PVC information, such as PVCs per hour, might also be more clinically relevant than the current method where every PVC is identified. This latter strategy might be most useful for isolated PVCs, which were the most common type in our study.

Since the CAST study, which is dated, research on the significance of PVCs has shifted in large part to outpatient populations, with a focus on the role that frequent PVCs might have on cardiomyopathies and/or heart failure (Marcus, 2020; Suba et al., 2021). Our study is unique in that no prior study has reported on six different PVC types and their

association with VT in ICU patients. We showed that isolated PVCs far outnumbered the other five types of PVCs examined in this study. The mean number of isolated PVCs was higher in the VT group, and these patients were more likely to have cardiac co-morbidities (i.e., reduced LVEF, previous IHD, PCI/CABG, and HF) known to be associated with an increased risk of VT (Baldzizhar et al., 2016; Koplan & Stevenson, 2009; Pedersen et al., 2014). However, the presence of isolated PVCs was no longer associated with VT in the adjusted logistic regression analysis. Our results may suggest that hospitals may be over-monitoring, especially for isolated PVCs. Thoughtful and data-driven decisions by the care team regarding activating PVC alarms should be factored into hospital-based alarm management strategies.

We found that the PVC counts for the six types we examined were highly skewed, regardless of the VT group (yes vs. no). For example, for isolated PVCs, the minimum and maximum counts ranged from zero to as high as 8,482. While not as disparate, similar wide minimum and maximum counts were observed for the other five PVC types. We accounted for this issue by using quartiles (isolated PVC, couplets, and run PVC) or tertiles (bigeminy, R-on-T, and trigeminy) with zero inflation. However, none of the six PVC types were associated with VT in both unadjusted and adjusted logistic regression models. Our findings show that some patients may generate a high number of PVC alarms yet are not at higher risk for VT. Other investigators examining arrhythmia alarms, not specifically PVCs, have reported similar findings regarding high alarm counts in a subset of patients (Cvach et al., 2015; Drew et al., 2014; Nguyen et al., 2020; Suba et al., 2022). Identifying this subgroup of patients could be useful when developing patient-specific alarm management strategies.

In general, clinicians carefully monitor for R-on-T type PVCs since they can trigger VT and/or VF (Drew et al., 2014), particularly in hospitalized patients who develop drug-induced QT-prolongation (Drew et al., 2010; Kay et al., 1983). Interestingly, we found R-on-T type PVCs were not associated with VT. However, it is important to note that a small number of patients had an R-on-T type PVC; therefore, our study's power to detect an association was low. Despite this limitation, our findings are similar to those of two prior studies. Chiladakis and co-workers (2000) examined 24-hour Holter recordings in acute MI patients treated with thrombolysis and found that R-on-T was rarely observed, and they were not associated with VT and/or VF. Likewise, Fries et al. (2003) found that R-on-T type PVCs rarely precipitated sustained VT in patients with an implanted cardioverter-defibrillator (ICD). While this study showed that R-on-T type PVCs rarely occurred, they did find that VT initiated by an R-on-T was more likely to lead to polymorphic VT than VT not initiated by an R-on-T.

Building on prior studies (Fries et al., 2003; Noda et al., 2004), we also found that R-on-T type PVCs were infrequent, but we did have a case of an R-on-T type PVC that resulted in VT that deteriorated into VF (Figure 1). Therefore, it would seem prudent and reasonable to keep this particular PVC alarm type activated. Classic ECG features (i.e., QT prolongation with a short-long-short R-R cycle followed by an R-on-T) that have been shown to be associated with Torsade de Pointes (TdP) (Drew et al., 2014) may be of particular interest. An algorithm that could recognize these classic features coupled with the QT interval might be more useful for identifying patients at high risk for developing TdP (Drew et al., 2014). A

future study with a larger sample of patients with this type of ECG and PVC pattern might help determine the prognostic value of a more precise arrhythmia alarm.

Limitations

Several limitations need consideration. The PVC alarms examined in this study were not annotated; thus, whether PVC events were true or false and if any PVCs were missed (false negatives) is unknown. However, one study that evaluated PVC detection algorithms reported that the accuracy of PVC detection was between 86% and 99% (Nabil & Reguig, 2015).

An additional limitation of our analysis was the small sample size, which lead to several difficulties in assessing our primary PVC covariates of interest. First is the large confidence intervals on our PVC covariates, indicating that there still may be a relatively strong effects of PVCs that we were simply not powered to detect (Hoenig & Heisey, 2001). Second, is our ability to adjust for potential confounders in the model. While we identified a number of potential important confounders, we were limited in the number of covariates that can be fit in the logistic regression (see Methods); however, we noted that the estimated coefficients from the adjusted and adjusted models were generally similar.

Another limitation is that our data were collected from one vendor; thus, the findings of this study may not apply to different ECG vendors. We used PVC count data as covariates in our models and did not analyze specific ECG characteristics (e.g., QT interval, prematurity index, or morphology), which may be important to explore in a future study. Our study was conducted at a quaternary academic medical center, which often cares for highly complex patients, often transferred from outside hospitals. Therefore, our sample may differ from ICU patients in other hospitals and may impact the generalizability of the findings. Nevertheless, our study used commercially available ECG monitoring devices and included consecutive patients admitted to three adult ICU specialties (i.e., medical-surgical, cardiovascular, and neuro/neurosurgery). Therefore, this study represents ‘real-world’ ICU clinical care, which is a strength of this study. It is also important to note that we examined only ICU patients; therefore, whether our results would apply to non-ICU patients is unknown.

In our analysis, we used a 24-hour time period to examine the association of PVCs and VT based on prior studies that examined IHCA (Do et al., 2015; Do et al., 2019). Different analytical approaches, such as the diagnostic yield proposed by Dziubiński et al. (2022), might be useful for future studies.

We were somewhat surprised that variables we hypothesized would be associated with VT, such as previous cardiac history, current cardiac diagnosis, and electrolyte disturbances were not significant in the multivariable logistic regression models. Our goal here was to identify patients at higher risk for VT based on their clinical characteristics. However, we did not find a significant association with VT when accounting for all variables. This may have been due to small sample sizes (limitation discussed above). We did not measure dynamic electrolyte changes, particularly K and Mg; rather, we examined K and Mg replacement. These fluctuations may be an important factor that predict patients at higher risk for

subsequent VT. We did not examine the presence of specific ECG abnormalities such as left/right BBB, left ventricular hypertrophy (LVH), and/or myocardial ischemia, which can increase the risk of VT. These abnormalities, coupled with the occurrence of PVC, would be important to study in a future investigation.

Finally, our analysis of in-hospital death was potentially biased since the time of death in our sample varied and/or occurred after the 24 hours selected for the PVC analysis (non-VT vs. VT groups). Several clinical factors could have confounded potential associations, including a worsening medical condition, medical procedures/surgery, or other medications that were not considered in this study.

CONCLUSION

PVCs measured 24 hours prior to a VT event were not associated with the occurrence of VT. It is possible that some hospitals in the United States and other counties have adopted the PVC monitoring practice standards published by AHA (i.e., “may” be considered) and do not activate these types of alarms. However, we hypothesize that many hospitals, like ours, continue to activate these types of alarms. Our study contributes important evidence supporting AHA’s Practice Standards for ECG Monitoring in Hospital Settings regarding PVC monitoring and highlights the need for larger studies to be conducted for more precise estimates, and for hospitals to potentially re-examine their PVC alarm management strategies. Future studies should additionally focus on examining potentially relevant PVC characteristics (e.g., new-onset, increased frequency) and specific ECG characteristics (e.g., coupling interval, QRS duration, BBB and/or LVH, morphology [right versus left ventricle origin], or concomitant QT interval prolongation) that could guide future algorithm development and improve continuous hospital-based ECG monitoring.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability:

The data that supports the findings of this study are available in the main text and supplementary material of this article.

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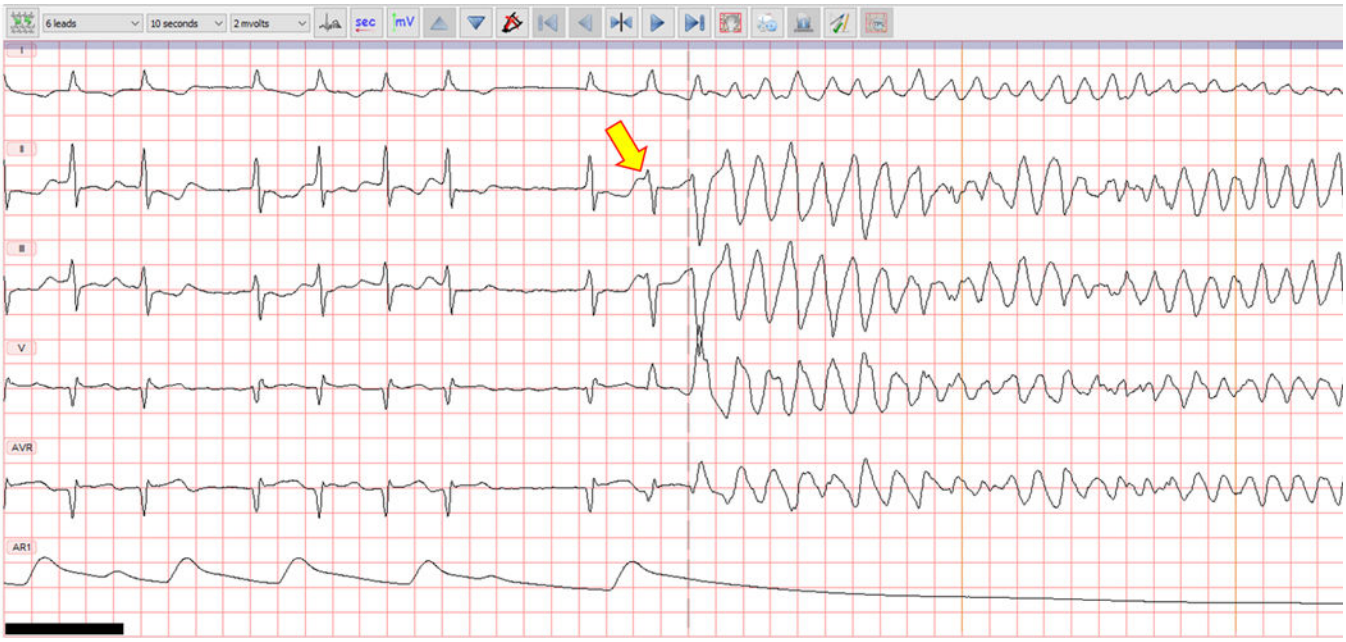

Figure 1.

An example of an R-on-T type premature ventricular complex (PVC) triggering ventricular tachycardia (VT) that deteriorated into ventricular fibrillation (VF). This ECG was from a 63 year-old male admitted to the ICU status post aspiration and pulseless electrical activity (PEA) arrest. The patient had history of heart failure (LVEF 35%) and atrial thrombosis. Note the R-on-T PVC (arrow) that proceeded the event. Also shown in the arterial blood pressure waveform (AR1) at the bottom of the tracing, which became flat with the occurrence of VT/VF.

Table 1.

Demographic and clinical characteristics of 445 intensive care unit (ICU) patients with and without ventricular tachycardia.

Demographic and Clinical Characteristics	Total (*N*=445) n (%)	Non-VT (*n*=397; 89%)	VT (*n*=48; 11%)	*p*-value [a]
Age, years, mean (SD)	60.0 (17.0)	60.1 (17.3)	58.7 (15.0)	*0.584*
Race				*0.142*
Asian	76 (17.1%)	71 (17.9%)	5 (10.4%)	
Black or African American	34 (7.6%)	28 (7.1%)	6 (12.5%)	
Native Hawaiian or Pacific Islander	8 (1.8%)	8 (2.0%)	0 (0.0%)	
Unknown (acute illness) or decline to state	58 (13.0%)	55 (13.9%)	3 (6.2%)	
White	269 (60.4%)	235 (59.2%)	34 (70.8%)	
Gender				*0.583*
Female	202 (45.4%)	182 (45.8%)	20 (41.7%)	
Male	243 (54.6%)	215 (54.2%)	28 (58.3%)	
Primary diagnosis				***< 0.001***
Cardiovascular	97 (21.8%)	73 (18.4%)	24 (50.0%)	
Medical-surgical	178 (40.0%)	164 (41.3%)	14 (29.2%)	
Neurological	170 (38.2%)	160 (40.3%)	10 (20.8%)	
Presence of PVC on 12-lead ECG at ICU admission (*N*=350)[b]	24 (6.9%)	23 (7.5%)	1 (2.3%)	*0.209*
Left ventricular ejection fraction (LVEF) (*N*=172)[c]				***< 0.001***
Preserved (LVEF >40%)	141 (82.0%)	125 (86.2%)	16 (59.3%)	
Reduced (LVEF ≤40%)	31 (18.0%)	20 (13.8%)	11 (40.7%)	
Clinical history				
Ischemic heart disease	71 (16.0%)	56 (14.1%)	15 (31.2%)	***0.002***
PCI/CABG	38 (8.5%)	28 (7.1%)	10 (20.8%)	***0.001***
Heart failure	44 (9.9%)	31 (7.8%)	13 (27.1%)	***< 0.001***
Medications[d]				
Antiarrhythmic drugs	105 (23.6%)	95 (23.9%)	10 (20.8%)	*0.633*
Proarrhythmic drugs	233 (52.4%)	205 (51.6%)	28 (58.3%)	*0.38*
Pro/antiarrhythmic drugs	35 (7.9%)	32 (8.1%)	3 (6.2%)	*0.66*
Magnesium replacement	129 (29.0%)	117 (29.5%)	12 (25.0%)	*0.519*
Potassium replacement	194 (43.6%)	167 (42.1%)	27 (56.2%)	*0.061*
Adverse outcome				
In-hospital cardiac arrest	11 (2.5%)	4 (1.0%)	7 (14.6%)	***< 0.001***
In-hospital death	49 (11.0%)	40 (10.1%)	9 (18.8%)	*0.07*

[a] Chi-square test, except for variable *Age* (t-test).

[b] Missing data in 95 patients (90 in non-VT group; 5 in VT group).

[c] Missing data in 273 patients (252 in non-VT group; 21 in VT group).

[d] Medications (antiarrhythmic, proarrhythmic, and pro/antiarrhythmic) and electrolyte replacement (magnesium and/or potassium) are compared between the groups using the 24-hour prior to the VT event (VT group) and during a 24-hour peak PVC count period (non-VT group).

Abbreviations: CABG, coronary artery bypass graft; ECG, electrocardiograph; ICU, intensive care unit; PCI, percutaneous coronary intervention; VT, ventricular tachycardia.

Table 2.

Distribution of six types of premature ventricular complexes (PVCs) among 445 intensive care unit (ICU) patients with and without ventricular tachycardia.

PVC Type	Total (*N*=445)	Non-VT Group (*n*=397)	VT Group (*n*=48)	*p*-value *
Isolated PVC				***0.031***
Mean (SD)	461.1 (1,111.7)	447.9 (1,125.4)	569.5 (995.6)	
Median (Q1, Q3)	51.0 (13.0, 279.0)	45.0 (12.0, 255.0)	103.0 (27.5, 682.2)	
Min - Max	0.0 – 8482.0	0.0 – 8482.0	0.0 – 4879.0	
Bigeminy				*0.232*
Mean (SD)	19.8 (113.1)	19.0 (109.8)	25.7 (138.4)	
Median (Q1, Q3)	0.0 (0.0, 1.0)	0.0 (0.0, 1.0)	0.0 (0.0, 2.0)	
Min - Max	0.0 – 1596.0	0.0 – 1596.0	0.0 – 953.0	
Trigeminy				*0.168*
Mean (SD)	19.3 (146.8)	20.5 (155.2)	9.2 (24.2)	
Median (Q1, Q3)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 1.2)	
Min - Max	0.0 – 2343.0	0.0 – 2343.0	0.0 – 139.0	
Couplet				*0.175*
Mean (SD)	23.6 (98.2)	20.4 (84.3)	50.0 (174.4)	
Median (Q1, Q3)	4.0 (1.0, 13.0)	4.0 (1.0, 13.0)	7.0 (2.0, 17.0)	
Min - Max	0.0 – 1,274.0	0.0 – 1,274.0	0.0 – 1,145.0	
R-on-T				*0.936*
Mean (SD)	2.2 (18.6)	2.2 (19.5)	1.7 (6.7)	
Median (Q1, Q3)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	
Min - Max	0.0 – 356.0	0.0 – 356.0	0.0 – 45.0	
Run PVCs				***0.032***
Mean (SD)	7.8 (59.1)	6.8 (59.7)	15.8 (53.2)	
Median (Q1, Q3)	1.0 (0.0, 3.0)	1.0 (0.0, 3.0)	2.0 (0.0, 5.0)	
Min - Max	0.0 – 1162.0	0.0 – 1162.0	0.0 – 300.0	

* Kruskal-Wallis test

Table 3.

Categorization of premature ventricular complex (PVC) covariates into tertiles or quartiles.

PVC Covariate	Quartiles Cut-off Points (*n*)			
	Group 1	Group 2	Group 3	Group 4
Isolated PVC	≤13 (118)	14–51 (106)	52–279 (110)	>279 (111)
Couplets	1 (122)	2–4 (106)	5–13 (108)	>13 (109)
Runs of PVC	0 (182)	1 (83)	2–5 (104)	>5 (76)

PVC Covariate	Tertiles Cut-off Points (*n*)		
	Group 1	Group 2	Group 3
Bigeminy	0 (311)	1–3 (68)	>3 (66)
R-on-T	0 (353)	1 (43)	>1 (49)
Trigeminy	0 (338)	1–7 (57)	>7 (50)

Table 4.

Association between premature ventricular complex (PVC) covariates and ventricular tachycardia (VT) and in-hospital death outcomes in 445 ICU patients, using logistic regression.

PVC covariates	Outcome: VT				Outcome: In-hospital death			
	Unadjusted model		Adjusted model*		Unadjusted model		Adjusted model**	
	OR (95% CI)	Overall *p*	OR (95% CI)	Overall *p*	OR (95% CI)	Overall *p*	OR (95% CI)	Overall *p*
Isolated								
14 – 51	1.94 (0.68, 5.55)		2.35 (0.77, 7.14)		4.7 (1.51, 14.6)		4.48 (1.41, 14.22)	
52 – 279	3.18 (1.20, 8.44)	0.048	3.67 (1.27, 10.57)	0.116	3.49 (1.09, 11.2)	0.005	3.18 (0.98, 10.37)	0.043
>279	3.14 (1.18, 8.35)		3.01 (0.97, 9.34)		5.52 (1.8, 16.9)		4.90 (1.47, 15.32)	
Bigeminy								
1 – 3	1.61 (0.75, 3.49)	0.463	1.44 (0.63, 3.26)	0.576	2.21 (1.03, 4.74)	0.011	1.94 (0.88, 4.27)	0.031
>3	1.29 (0.56, 2.96)		0.84 (0.33, 2.10)		2.81 (1.35, 5.83)		2.60 (1.22, 5.54)	
Trigeminy								
1 – 7	0.89 (0.33, 2.38)	0.119	0.81 (0.29, 2.26)	0.350	0.86 (0.32, 2.3)	0.132	0.65 (0.23, 1.85)	0.464
>7	2.31 (1.06, 5.04)		1.75 (0.75, 4.10)		2.24 (1.03, 4.87)		1.41 (0.49, 3.34)	
Couplet								
2 – 4	0.94 (0.37, 2.35)		0.81 (0.31, 2.14)		1.45 (0.58, 3.66)		1.50 (0.58, 3.88)	
5 – 13	1.5 (0.65, 3.47)	0.573	1.07 (0.44, 2.60)	0.949	1.57 (0.63, 3.88)	0.263	1.28 (0.40, 3.31)	0.747
>13	1.49 (0.64, 3.43)		0.93 (0.38, 2.32)		2.32 (0.99, 5.45)		1.63 (0.65, 4.08)	
R-on-T								
1	0.19 (0.03, 1.43)	0.051	0.17 (0.02, 1.32)	0.189	0.83 (0.28, 2.43)	0.901	0.70 (0.22, 2.26)	0.796
>1	1.57 (0.69, 3.59)		1.29 (0.53, 3.13)		1.12 (0.45, 2.81)		0.82 (0.30, 2.23)	
Run PVCs								
1	1.03 (0.40, 2.62)		0.94 (0.35, 2.52)		1.03 (0.40, 2.62)		0.73 (0.28, 1.94)	
2 – 5	1.88 (0.88, 4.01)	0.248	1.62 (0.73, 3.58)	0.607	1.59 (0.73, 3.49)	0.111	1.33 (0.58, 3.01)	0.305
>5	1.88 (0.82, 4.32)		1.23 (0.50, 3.03)		2.51 (1.15, 5.51)		1.81 (0.78, 4.17)	

* Logistic model adjusted for confounders identified in the stepwise fit (see Suppl. Table A). Sensitivity analysis of dichotomized PVC covariates is presented in Supp. Table B.

** Logistic model adjusted for confounders identified in the stepwise fit (see Suppl. Table C). Sensitivity analysis of dichotomized PVC covariates is presented in Supp. Table D.