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Actionable Ventricular Tachycardia During In-hospital ECG Monitoring and its Impact on Alarm Fatigue

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Abstract

Background—Ventricular tachycardia (V-tach) is the most common lethal arrhythmia, yet 90% are false and contribute to alarm fatigue. We hypothesize that some *true* V-tach also causes alarm fatigue because current criteria are too sensitive (i.e., ≥ 6 beats ≥ 100 beats/minute [bpm]).

Purpose—This study was designed to determine: 1) the proportion of clinically actionable true V-tach events; 2) whether true actionable versus non-actionable V-tach differs in terms of heart rate and/or duration (seconds); and 3) if actionable V-tach is associated with adverse outcomes.

Methods—This was a secondary analysis in 460 ICU patients. Electronic health records were examined to determine if a V-tach event was actionable or non-actionable. A*ctionable* V-tach was defined if a clinical action(s) was taken within 15 minutes of its occurrence (i.e., new and/or change of medication, defibrillation, and/or lab test). Maximal heart rate and duration for each V-tach event was measured from bedside monitor ECGs. Adverse patient outcomes included a code blue event, and/or death.

Results—In 460 ICU patients, 50 (11%) had 151 true V-tach events (range 1 to 20). Of the 50 patients, 40 (80%) had only non-actionable V-tach (97 events); 3 (6%) had both actionable and non-actionable V-tach (32 events); and 7 patients (14%) had only actionable V-tach (23 events). There were differences in duration comparing actionable versus non-actionable V-tach (mean 56.19,+/− 116.87 seconds versus 4.28, +/− 4.09 seconds; p = 0.001) and maximal heart rate (188.81 +/− 116.83 bpm versus 150.79 +/− 28.26 bpm; p = 0.001). Of the 50 patients, 3 (6%) had a code blue, two died and all were in the actionable V-tach group.

Conclusions—In our sample, less than 1% experienced a code blue following true V-tach. Heart rate and duration for actionable V-tach was much faster and longer than that for non-actionable V-tach. Current default settings typically used for ECG monitoring (i.e., ≥ 6 beats ≥ 100 bpm) appears to be too conservative and can lead to crisis/red level nuisance alarms that contribute to

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alarm fatigue. A prospective study designed to test whether adjusting default settings to these higher levels is safe for patients, is needed.

Ventricular tachycardia (V-tach) is one of the most commonly occurring alarms during continuous electrocardiographic (ECG) monitoring in the hospital setting. In a comprehensive investigation conducted in an intensive care unit (ICU), of 4,811 critical arrhythmia alarms (i.e., asystole, ventricular fibrillation, and V-tach), 80% were for V-tach.[1] During V-tach, the ventricles take over the heart's rhythm at a much faster heart rate than is normal; thus, the usual sequence of atrial contraction followed by ventricular contraction is circumvented. The asynchrony and rapid heart rate during V-tach impairs cardiac output and thus, circulation to the brain, heart and other major organs of the body. Because V-tach can deteriorate into ventricular fibrillation, prompt recognition and treatment (i.e., medications and/or defibrillation) is critical.

V-tach is considered a lethal arrhythmia, yet as many as 80 to 90%[1–9] of V-tach alarms are false and are a major source of alarm fatigue. Alarm fatigue occurs when nurses and other clinicians exposed to alarms are desensitized by frequently occurring alarms, most of which are false or clinically irrelevant.[7, 10–20] Alarm sounds may become background noise that is assimilated into the normal ICU workflow. Over time, clinicians manage alarm fatigue by: (1) silencing alarms without assessing the patient; (2) lowering the alarm volume; (3) delaying a response to an alarm(s) by assuming it is false; and/or (4) permanently disabling alarms altogether. These actions place patients at risk for serious adverse events, including death, because true alarms are missed. Regulatory agencies,[21, 22] safety organizations[23–25] and professional associations[26, 27] have identified alarm fatigue as an important clinical problem that requires evidence based solutions to reduce patient harm.

V-tach alarms are configured as latching alarms (i.e., critical/red), which means they must be physically silenced by the nurse and/or monitor watcher. The nurse is then responsible for determining if the alarm is true or false and taking the necessary actions for acute treatment (e.g., activating code blue, defibrillation, etc) and/or contacting a provider. Providers who are called, must also decide if the alarm is true or false and if any action(s) are required. Given that the vast majority of V-tach alarms are deemed false, it is not surprising that VT alarms are a major source of alarm fatigue for the entire care team. Moreover, studies show that even true V-tach alarms are often non-actionable (i.e., non-sustained or no treatment needed).[1, 28] Thus, there is a two-fold problem. First, true V-tach events could be missed because they are buried within frequently occurring false alarms[29] and second, there exists the potential to over-treat patients due to false or non-actionable V-tach alarms. The latter could lead to unnecessary medications and or procedures placing vulnerable patients at further risk.

To address false alarms, several investigations have examined algorithm based solutions such as signal quality measures, accelerometers to identify and account for motion artifact, and coupling the ECG waveform(s) with other physiologic parameters (i.e., SpO2, arterial blood pressure) as a way to reduce false positives and identify clinically actionable V-tach alarms.[2, 30–34] While these approaches have demonstrated some success, there are problems including; suppression of true V-tach alarms;[2] most ICU patients do not have invasive

pressure lines to corroborate with the ECG, and most of the studies have been done in a laboratory based setting; hence, whether these strategies are safe for patients is largely unknown.[20] Additionally, solutions using other physiologic parameters (i.e., SpO2, arterial blood pressure) would not be possible in non-ICU patients who don't have these devices to couple with the ECG. While ECG algorithm-based solution would likely have broad application to all hospitalized patients with continuous ECG monitoring, until these solutions exist in current clinical practice, other potential strategies need investigation. For example, are there adjustments that can be made to current default settings that might reduce unnecessary (nuisance) V-tach alarms; thus, alarm fatigue? A better understanding of possible ECG features and patient outcomes could not only be useful for new algorithm development, but also for hospital clinicians who determine optimal default settings for bedside monitoring.

Most current bedside monitors are configured to alarm for V-tach using the following criteria; six or more consecutive wide QRS complexes at a rate > 100 beats/minute. We hypothesize these criteria are too sensitive even when V-tach is true and in turn, contribute to alarm fatigue. Configuring default settings to alarm for V-tach at a higher heart rate and/or at a longer duration might be one immediate solution to identify actionable versus non-actionable V-tach alarms. With this in mind, the purpose of this study was to determine: 1) the proportion of clinically actionable true V-tach alarms; 2) whether true actionable versus non-actionable V-tach differs in terms of heart rate and/or duration (seconds); and 3) if actionable V-tach is associated with adverse outcomes (i.e., code blue, cardioversion/defibrillation, death).

Methods

Design/Setting/Sample

The present investigation is a secondary analysis using data from the Alarm Study, which has been described in detail previously.[1] Briefly, the Alarm Study was a prospective observational study conducted within a large urban tertiary-quaternary medical center. All physiologic data from the bedside monitor were collected from the medical center's 77 adult ICU beds during a one month study period. The adult ICU's were of the following type; cardiac (16 beds), medical-surgical (32 beds), and neurological (29 beds). The university's Committee on Human Research approved the observational study with waiver of written informed consent because all ICU patients have physiologic monitoring as a part of their routine care and the data were not used to make clinical decisions. Hence, 461 consecutive ICU patients were included in the study. We also had approval from the Committee on Human Research to collect demographic, clinical history, lab tests, procedures, patient outcomes, length of ICU/hospital stay and final discharge diagnosis.

Bedside Monitors and Data Collection Method

All physiologic waveforms (e.g., ECG, arterial blood pressure, pulse oximetry, and respirations), numeric vital signs measurements, alarm parameter settings, and both audible and inaudible alarms (e.g., arrhythmia, parameter, and technical) were collected from each of the 77 bedside monitors using a sophisticated research infrastructure (Figure 1). Each

ICU bed was equipped with a Solar 8000i monitor and all were connected to a central monitoring station (version 5.4 software, GE Healthcare, Milwaukee, WI). A CARESCAPE Gateway system (GE Healthcare, Milwaukee, WI) enabled data to securely pass out of the network to an external server for retrospective analysis. BedMasterEx software (Excel Medical Electronics, Inc, Jupiter, FL) was used to store and organize physiologic waveforms, vital signs, alarms and alarm settings in a relational database (SQL ServerTM) in a flat file format (XML). Our team developed an application to parse the XML files, detect and repair gaps and/or alternations of signal channel configurations, and assemble the waveform data into multiple binary files, which can then be analyzed using analytical programs including MATLAB, Excel, and LabChart Reader for offline analysis.

Electrocardiographic Data and Alarm Annotation

A Mason-Likar 5-electrode lead configuration was used to record seven ECG leads including leads I, II, III, aVR, aVL, aVF, and one V lead, which is V1 at our hospital. Six audible ECG arrhythmia alarms were annotated by a team of doctorally prepared nurse-scientists and included; asystole, ventricular fibrillation, V-tach, accelerated ventricular rhythm, pause, and ventricular bradycardia. All of the annotators completed a 10-week course in clinical electrocardiography and a 3-hour alarm annotation certification course taught by the principal investigator of the Alarm Study. Each arrhythmia alarm was determined to be true or false using a standardized protocol. There was 95% agreement when determining true or false positive alarms among the annotators (Cohen's Kappa score of 0.86).[1] For the present study, only the true V-tach alarms were examined. Table 1 shows the algorithm criteria used by the bedside monitor to identify V-tach, as well as the operational definitions and process used by the annotators to determine true versus false V-tach alarms.

Actionable versus Non-Actionable Ventricular Tachycardia

Electronic health records (EHR) were manually examined to determine if a true V-tach alarm was actionable versus non-actionable. A true V-tach alarm was considered *actionable* if there was a clinical action taken within 15 minutes of its occurrence (i.e., new and/or change of medication, pacemaker, cardioversion or defibrillation, and/or lab test). Additionally, the EHR data was carefully examined (i.e., vital signs, nursing and provider notes, medication record, lab tests, etc.) one hour before and after the time of the true alarm to ensure actions taken by the clinical team were captured. The procedure for nurses to document a true ECG alarm at our institution includes scanning the ECG rhythm strip printed from the central monitoring station into the EHR; hence, we also looked for a scanned ECG to determine if the V-tach was acknowledged by the nurse taking care of the patient.

Outcomes

We also examined the EHR to determine if an adverse patient outcome was associated with the V-tach alarm around the time of the alarm or anytime during the ICU admission. Adverse patient outcomes were defined as a code blue event, cardioversion/defibrillation and/or death.

Statistical Analysis

Data were analyzed using SPSS 25.0 (IBM Corporation, 2017). Descriptive statistics were used to evaluate demographics (i.e., age, gender, race and ethnicity) as well as clinical history, ICU type (i.e., cardiac, medical-surgical, or neurological), and patient outcomes. Data are expressed as means ± standard deviation and percentages. Categorical variables were examined for differences using chi-square analyses. The Students t-test was used to examine differences for continuous variables. An overall p-value of < 0.05 was used as the critical value to determine statistical significance. While we report patient level data, the unit of analysis for assessing actionable versus non-actionable V-tach was each true V-tach alarm event. Differences in heart rate and/or duration (seconds) for each V-tach event was tested using the Students t-test.

Results

Of the 461 ICU patients included in the primary study, 183 had 3,861 V-tach alarms. Of the total number of V-tach alarms, 3,352 (86.8%) were determined to false positive. Of the 183 patients, 51 (28%) had 484 true V-tach alarms (range 1 to 333). One of the 51 patients with true V-tach, was diagnosed with electrical storm and had 333 (69%) of the 484 true V-tach alarms. The patient had an extensive clinical history including; hypertension, coronary artery disease, diabetes, and ventricular tachycardia. This one patient was excluded from the current analysis because these data would skew the variables of interest in the present study. Therefore, our secondary analysis included 50 (11%) ICU patients with 151 true V-tach alarms (range 1 to 20).

Actionable versus Non-actionable Ventricular Tachycardia

Table 2 shows the demographics, clinical history, ICU unit type, and outcome variables for the entire sample (n = 460); patients with no true V-tach (n = 410); and the 50 patients with one or more true V-tach events. There were no differences between the two V-tach groups with regards to sex, age, BMI, race, or ethnicity. A higher proportion of patients with true V-tach were admitted to the cardiac ICU. There were no differences with regards to the presence of a bundle branch block (8% versus 16%; p = 0.052), or altered mental status when comparing the two V-tach groups (no true V-tach versus true V-tach). However, there were proportional differences among those with a ventricular pacer (no true V-tach 2% versus true V-tach 12%; p = 0.001) and among those treated with mechanical ventilation (no true V-tach 32% versus true V-tach 52%; p = 0.005). A code blue event at any time during the ICU admission was more common among the V-tach group as compared to the no V-tach group (16% versus 1.2%; p = 0.001), as was all-cause mortality was higher in the V-tach group (16% versus 6%; p = 0.014).

Table 3, shows the final discharge diagnosis for the sample and a comparison of the no true V-tach group to the true V-tach group based on the discharge diagnosis. The overall p-value was statistically significant. Post-hoc analysis, using a Bonferroni correction, found that true V-tach was more likely to occur in patients with a primary discharge diagnosis that was cardiac in nature (i.e., arrhythmia, heart failure, myocardial infarction).

Table 4, is a comparison of the actionable versus non-actionable V-tach groups. Among the 50 patients, 10 (20%) had one or more actionable V-tach events. The median number of events in this group was two (range 1 to 9). The median number of alarms in the 40 patients with non-actionable V-tach was one (range 1 to 20).

Table 4, also shows the data for the 151 true V-tach alarm, using the alarm as the unit of analysis. Of the 151 total V-tach alarms, 31 (21%) were actionable and 121 (79%) were non-actionable. The most common actions were new antiarrhythmic drug (n=24, 77%) and/or lab test (n=4, 13%). There were differences between actionable versus non-actionable V-tach events in maximal heart rate (188.81 SD +/− 116.83 beats/minute versus 150.79 +/− 28.26 beats/minute; p = 0.001) and duration (mean 56.19, SD +/− 116.87 seconds versus 4.28, SD +/− 4.09 seconds; p = 0.001).

Because a patient could have more than one true V-tach alarm and/or both actionable and non-actionable V-tach, we further sub-divided the 50 patients into three groups: (1) actionable only; (2) both actionable and non-actionable, and; (3) non-actionable only. We compared heart rate and duration among the three groups. As illustrated in Figure 2, in 7 (14%) of the 50 patients there were 23 actionable only V-tach alarms (range 1 to 9). The mean heart rate in this group was 201 ± 9 beats/minute and the mean duration was 21 ± 1 seconds. Three patients (6%) had both actionable and non-actionable V-tach events. This group had 32 total alarms, nine alarms were actionable (range 1 to 7) and 24 alarms were non-actionable (range 2 to 17). The mean heart rate and duration for the actionable alarms in this group, was 150 ± 29 beats/minute and 61 ± 99 seconds. There were 40 (80%) patients in the non-actionable only alarm group who had 97 non-actionable V-tach events (range 1 to 20). The mean heart rate and duration for the non-actionable only group was 150 ± 26 beats/minute and 5 ± 4 seconds.

Statistical tests examining potential differences in heart rate and duration between the three groups were performed. There were heart rate differences between the actionable only group versus both actionable/non-actionable and only non-actionable, respectively (201 beats/minute versus 150 beats/minute versus 150 beats/minute; p = 0.001). There were differences in V-tach duration when comparing the actionable only group versus only non-actionable group (21 ± 1 seconds versus 5 ± 4 seconds; p = 0.001), but no difference in duration between the actionable only group versus both actionable/non-actionable (21 ± 1 seconds versus 61 ± 99 seconds; p = 0.0586).

Outcomes Among Patients with True V-tach

When examining the 50 patients with true V-tach (Table 3), 3 (6%) of the patients in the actionable V-tach group had a code blue event versus none in the non-actionable V-tach group. As illustrated in Figure 2, two of the code blue events occurred in the only actionable group (2/7; 29%) and one in the both actionable and non-actionable group (1/3; 33%). There were no code blue events among the non-actionable V-tach group. Both of the patients in the actionable only group who had a code blue event died soon after the event. The other patient who coded in the group with both actionable and non-actionable V-tach, was successfully treated for their V-tach and then transferred from the ICU to the step down unit.

Discussion

Multi-parameter monitoring, including ECG monitoring, in the ICU remains unsatisfactory as evidenced by the well-known alarm fatigue problem. V-tach is among the most problematic lethal arrhythmia alarm it occurs frequently and has a high false positive rate. To our knowledge, this appears to be the first study to examine the frequency of actionable versus non-actionable true V-tach among adult ICU patients. The main findings of our study in 460 consecutive ICU patients, includes: (1) 11% of patients experience true V-tach; (2) only 2% of patients have actionable V-tach (i.e., new and/or adjustment of a drug or lab test); (3) fewer than 1% of patients experience a code blue event following an actionable V-tach event; (4) the heart rate and duration of actionable V-tach is much longer and faster than that for non-actionable V-tach; (5) a code blue event is more likely to occur when the duration is long (> 60 seconds) and/or the heart rate is very rapid (> 190 beats/minute).

Similar to Winkler et al.,[35] we found that V-tach was rather uncommon. In their study, non-sustained V-tach occurred in 11% of their sample and sustained V-tach in 1%. Similarly, we found that 11% of our sample had one or more true V-tach alarms. Additionally, we found that in only 2% of patients was an action taken, most often a new/change of medication. The overall rate of a code blue was essentially identical, 3% in their sample and 2.8% in our study. However, in fewer than 1% of our sample was the code blue event associated with V-tach, suggesting a very small proportion of V-tach is accompanied with an adverse outcome. It should be noted, that the study by Winkler and colleagues included patients diagnosed with acute coronary syndrome admitted to a telemetry unit, while we studied only ICU patients (i.e., cardiac, medical/surgical, neurological). Not surprisingly, we found those discharge with a cardiac diagnosis were more likely to have true V-tach. In addition, we found that higher a proportion of ICU patients with a ventricular pacer or being treated with mechanical ventilation had true V-tach, which may be important risk factors for clinicians to consider. Despite these differences, both studies show that V-tach is relatively uncommon. This raises questions about how best to monitor for clinically important V-tach, particularly given that the vast majority of V-tach alarms are false and only a small number are actionable and/or associated with an untoward patient outcome.

Current practice standards for in-hospital ECG monitoring assigned arrhythmia monitoring for non-sustained V-tach (< 30 seconds) as a Class IIB; Level of Evidence C recommendation (i.e., may be considered) because this rhythm is not typically immediately life-threatening, except in select patients (i.e., cardiac disease, myocardial infarction, post arrest).[36] This recommendation is supported by another practice guideline for the management of V-tach and sudden cardiac death [37] and other primary research studies.[1, 35] Our findings suggest specific ECG features should be considered for in-hospital monitoring and clinical decision-making. In our entire sample, we found both maximal heart and duration were associated with actionable V-tach. However, in a more detailed analysis examining patients in the following groups; only actionable V-tach, both actionable and non-actionable V-tac, or only non-actionable V-tach; we found two important features were associated with actionable V-tach: (1) V-tach of relatively short duration, but with a rapid heart rate (200 beats/minute and 20 seconds); and, (2) V-tach with moderately rapid heart

rate of longer duration (150 beats/minute and 60 seconds). These data suggest both duration and maximal heart rate are important markers for identifying high risk patients with V-tach.

Importantly, the V-tach features we identified in our study are considerably different than the default settings typically used for in-hospital monitoring (i.e., ≥ 6 consecutive wide QRS complexes > 100 beats/minute). The current default settings appear to be too sensitive, which means unnecessary, or nuisance, crisis/red level alarms will occur and contribute to alarm fatigue. Alarm fatigue from V-tach alarms is even more problematic given the high rate of false positive alarms (nearly 90%). However, whether adjustments to current default settings (higher heart rate and longer duration) would reduce false alarms is not known and needs further study. Despite this, it would appear that adjusting current default settings for > 130 beats/minute and a duration of > 20 seconds and might improve identification of actionable V-tach. However, further research is needed to determine whether these settings reduce the number of V-tach alarms without negatively impacting patient outcomes.

Our findings are consistent with outpatient studies that examined patients without significant heart disease and found that non-sustained V-tach was not associated with increased mortality at both short and long-term follow-up.[38–40] One study showed that additional testing after non-sustained V-tach was identified, had very low diagnostic yield for future adverse events.[40] Aggressive treatment for any occurrence of V-tach in ICU patients, who are already vulnerable from multiple other serious clinical problems, should be carefully considered. Rather, assessment for V-tach characteristics such as heart rate, duration, and/or other important clinical history (i.e., cardia disease) should be carefully evaluated prior to aggressive treatment. Interestingly, we found that in 40 patients who had 97 true V-tach alarms, no clinical action was taken and none had a code blue event associated with their V-tach event. This suggests that V-tach alarms of short duration even at a relatively fast heart rate (5 seconds; 150 beats/minute), may not require treatment. However, our findings are based upon retrospective analysis of EHR documentation and therefore, it would be prudent to re-evaluate these findings in a prospective study using a much larger sample.

Limitations

This was a retrospective study, hence, the inherent limitations of using previously documented EHR data is an important drawback of this study. It is possible that communication between nurses and providers did occur at the time of the V-tach event, but was not documented in the EHR. Therefore, the thoughts and ultimate decision clinicians made about how to manage the V-tach alarms may not have been fully captured in our study. Finally, it is possible that alarms found to have no clinical action(s) may have been missed due to alarm fatigue. However, one could argue that this is not likely since none of the non-actionable V-tach events lead to a code blue. Because of these limitations, solid conclusions about how nurses and providers evaluate and manage V-tach alarms remains unknown. We did not collect each patient's detailed cardiac history (i.e., prior myocardial infarction, heart failure, ejection fraction), clinical data (i.e., electrolytes, other lab, physiologic data), and/or all prescribed medications. Thus, how these factors may be associated with the occurrence of V-tach, or how/why the V-tach was managed is not known. Future prospective studies, therefore, are needed to evaluate what constitutes clinically significant V-tach events and

determine what human factors go into decision making during in-hospital ECG monitoring. Such a design would also shed light on the impact, if any, that V-tach alarms have on alarm fatigue and help guide interventions.

Conclusions

In the present study, we found that just over 10% of ICU patients experience true V-tach, while only 2% have an action taken (i.e., new/change medication, lab test). Fewer than 1% of the ICU patients in our study experience a code blue event following V-tach. Actionable V-tach is much longer and faster than that of non-actionable V-tach. Finally, current default settings used in most bedside monitors for identifying V-tach (> six beats of wide QRS's > 100 beats/minute) appears to be too sensitive, which can lead to crisis/red level nuisance alarms that contribute to alarm fatigue. Until improvements to current algorithms are introduced to reduce false V-tach alarms, adjusting default settings seems to be a reasonable next step in this line of inquiry. A prospective study designed to test whether adjustments to default alarm parameters for V-tach (i.e., 130 beats/minute, > 20 seconds) and whether this is safe for patients would be extremely useful.

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References Cited

1. Drew BJ, Harris P, Zegre-Hemsey JK, Mammone T, Schindler D, Salas-Boni R, Bai Y, Tinoco A, Ding Q, and Hu X. Insights into the problem of alarm fatigue with physiologic monitor devices: a comprehensive observational study of consecutive intensive care unit patients. PLoS One, 2014 9(10): p. e110274. [PubMed: 25338067]
2. Baumgartner B, Rodel K, and Knoll A. A data mining approach to reduce the false alarm rate of patient monitors. Conf Proc IEEE Eng Med Biol Soc, 2012. 2012: p. 5935–8.
3. Cvach M, Rothwell KJ, Cullen AM, Nayden MG, Cvach N, and Pham JC. Effect of altering alarm settings: a randomized controlled study. Biomed Instrum Technol, 2015 49(3): p. 214–22. [PubMed: 25993585]
4. Dandoy CE, Davies SM, Flesch L, Hayward M, Koons C, Coleman K, Jacobs J, McKenna LA, Olomajeye A, Olson C, Powers J, Shoemaker K, Jodele S, Alessandrini E, and Weiss B. A team-based approach to reducing cardiac monitor alarms. Pediatrics, 2014 134(6): p. e1686–94. [PubMed: 25384493]
5. Harris PR, Zegre-Hemsey JK, Schindler D, Bai Y, Pelter MM, and Hu X. Patient characteristics associated with false arrhythmia alarms in intensive care. Ther Clin Risk Manag, 2017 13: p. 499–513. [PubMed: 28458554]
6. Rosman EC, Blaufox AD, Menco A, Trope R, and Seiden HS. What are we missing? Arrhythmia detection in the pediatric intensive care unit. J Pediatr, 2013 163(2): p. 511–4. [PubMed: 23453551]
7. Ruppel H, Funk M, and Whittemore R. Measurement of Physiological Monitor Alarm Accuracy and Clinical Relevance in Intensive Care Units. Am J Crit Care, 2018 27(1): p. 11–21. [PubMed: 29292271]
8. Sendelbach S, Wahl S, Anthony A, and Shotts P. Stop the Noise: A Quality Improvement Project to Decrease Electrocardiographic Nuisance Alarms. Crit Care Nurse, 2015 35(4): p. 15–22; quiz 1p following 22. [PubMed: 26232798]

9. Sowan AK, Gomez TM, Tarriela AF, Reed CC, and Paper BM. Changes in Default Alarm Settings and Standard In-Service are Insufficient to Improve Alarm Fatigue in an Intensive Care Unit: A Pilot Project. JMIR Hum Factors, 2016 3(1): p. e1. [PubMed: 27036170]
10. Cvach M Monitor alarm fatigue: an integrative review. Biomed Instrum Technol, 2012 46(4): p. 268–77. [PubMed: 22839984]
11. Cvach MM, Currie A, Sapirstein A, Doyle PA, and Pronovost P. Managing clinical alarms: using data to drive change. Nurs Manage, 2013 44(11 Safety Solutions): p. 8–12.
12. Deb S and Claudio D. Alarm fatigue and its influence on staff performance. IIE Transactions on Healthcare Systems Engineering, 2015 5(3): p. 183–196.
13. Funk M, Clark JT, Bauld TJ, Ott JC, and Coss P. Attitudes and practices related to clinical alarms. Am J Crit Care, 2014 23(3): p. e9–e18. [PubMed: 24786820]
14. Graham KC and Cvach M. Monitor alarm fatigue: standardizing use of physiological monitors and decreasing nuisance alarms. Am J Crit Care, 2010 19(1): p. 28–34; quiz 35. [PubMed: 20045845]
15. Konkani A and Oakley B. Noise in hospital intensive care units--a critical review of a critical topic. J Crit Care, 2012 27(5): p. 522 e1–9.
16. Lewis CL and Oster CA. Research Outcomes of Implementing CEASE: An Innovative, Nurse-Driven, Evidence-Based, Patient-Customized Monitoring Bundle to Decrease Alarm Fatigue in the Intensive Care Unit/Step-down Unit. Dimens Crit Care Nurs, 2019 38(3): p. 160–173. [PubMed: 30946125]
17. Paine CW, Goel VV, Ely E, Stave CD, Stemler S, Zander M, and Bonafide CP. Systematic Review of Physiologic Monitor Alarm Characteristics and Pragmatic Interventions to Reduce Alarm Frequency. J Hosp Med, 2016 11(2): p. 136–44. [PubMed: 26663904]
18. Sendelbach S and Funk M. Alarm fatigue: a patient safety concern. AACN Adv Crit Care, 2013 24(4): p. 378–86; quiz 387–8. [PubMed: 24153215]
19. Sowan AK and Reed CC. A Complex Phenomenon in Complex Adaptive Health Care Systems-Alarm Fatigue. JAMA Pediatr, 2017 171(6): p. 515–516. [PubMed: 28394991]
20. Winters BD, Cvach MM, Bonafide CP, Hu X, Konkani A, O'Connor MF, Rothschild JM, Selby NM, Pelter MM, McLean B, Kane-Gill SL, Society A for Critical Care Medicine, and F. Alert Fatigue Task. Technologic Distractions (Part 2): A Summary of Approaches to Manage Clinical Alarms With Intent to Reduce Alarm Fatigue. Crit Care Med, 2017.
21. The Joint Comission. Medical Device Alarms Safety in Hospitals, in Sentinal Event Alert T.J. Commission, Editor. 2013 p. 1–3.
22. The Joint Commission. National Patient Safety Goal. 2014 [cited 2014; Available from: http://www.jointcommission.org/assets/1/18/JCP0713_Announce_New_NSPG.pdf.
23. ECRI. Top 10 Health Technology Hazards for 2016. 2016.
24. Association for the Advancement of Medical Instrumentation, C.f.R.D.H., U S A Food & Drug Administration A siren call to action: priority issues from the medical device alarms summit. 2011.
25. Association for the Advancement of Medical Instrumentation. Clinical Alarms. 2011; Available from: http://www.aami.org/publications/summits/2011_Alarms_Summit_publication.pdf Accessed October 2015.
26. American Association of Critical Care Nurses. Alarm Fatigue 2017; Available from: https://www.aacn.org.
27. American Nurses Association. Medical Alarm Safety in Hospitals. 2015 [cited 2018; Available from: http://www.nursingworld.org/MainMenuCategories/ThePracticeofProfessionalNursing/Improving-Your-Practice/One-Strong-Voice-Clinically-Speaking/Medical-Alarm-Safety-in-Hospitals.html
28. Allan SH, Doyle PA, Sapirstein A, and Cvach M. Data-Driven Implementation of Alarm Reduction Interventions in a Cardiovascular Surgical ICU. Jt Comm J Qual Patient Saf, 2017 43(2): p. 62–70. [PubMed: 28334564]
29. Nguyen SC, Suba S, Hu X, and Pelter MM. Double trouble: Patients with both true and false ECG arrhythmia alarms and the impact on alarm fatigue. Crit Care Nurs, 2019 In Press.
30. Aboukhalil A, Nielsen L, Saeed M, Mark RG, and Clifford GD. Reducing false alarm rates for critical arrhythmias using the arterial blood pressure waveform. J Biomed Inform, 2008 41(3): p. 442–51. [PubMed: 18440873]

31. Borowski M, Siebig S, Wrede C, and Imhoff M. Reducing false alarms of intensive care online-monitoring systems: an evaluation of two signal extraction algorithms. Comput Math Methods Med, 2011. 2011: p. 143480.
32. Desai K, Lexa M, Matthews B, and Genc S. Hemodynamic-impact-based prioritization of ventricular tachycardia alarms. Conf Proc IEEE Eng Med Biol Soc, 2014. 2014: p. 3456–9.
33. Li Q and Clifford GD. Signal quality and data fusion for false alarm reduction in the intensive care unit. J Electrocardiol, 2012 45(6): p. 596–603. [PubMed: 22960167]
34. Salas-Boni R, Bai Y, Harris PR, Drew BJ, and Hu X. False ventricular tachycardia alarm suppression in the ICU based on the discrete wavelet transform in the ECG signal. J Electrocardiol, 2014 47(6): p. 775–80. [PubMed: 25172188]
35. Winkler C, Funk M, Schindler DM, Hemsey JZ, Lampert R, and Drew BJ. Arrhythmias in patients with acute coronary syndrome in the first 24 hours of hospitalization. Heart Lung, 2013 42(6): p. 422–7. [PubMed: 23972554]
36. Sandau KE, Funk M, Auerbach A, Barsness GW, Blum K, Cvach M, Lampert R, May JL, McDaniel GM, Perez MV, Sendelbach S, Sommargren CE, Wang PJ, American C Heart Association Council on, N. Stroke, C. Council on Clinical, and Y. Council on Cardiovascular Disease in the. Update to Practice Standards for Electrocardiographic Monitoring in Hospital Settings: A Scientific Statement From the American Heart Association. Circulation, 2017 136(19): p. e273–e344. [PubMed: 28974521]
37. Al-Khatib SM, Stevenson WG, Ackerman MJ, Gillis AM, Bryant WJ, Hlatky MA, Callans DJ, Granger CB, Curtis AB, Hammill SC, Deal BJ, Joglar JA, Dickfeld T, Kay GN, Field ME, Matlock DD, Fonarow GC, Myerburg RJ, and Page RL. 2017 AHA/ACC/HRS Guideline for Management of Patients With Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death: Executive Summary: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. Heart Rhythm, 2017.
38. Fleg JL and Kennedy HL. Long-term prognostic significance of ambulatory electrocardiographic findings in apparently healthy subjects greater than or equal to 60 years of age. Am J Cardiol, 1992 70(7): p. 748–51. [PubMed: 1381549]
39. Kennedy HL, Whitlock JA, Sprague MK, Kennedy LJ, Buckingham TA, and Goldberg RJ. Long-term follow-up of asymptomatic healthy subjects with frequent and complex ventricular ectopy. N Engl J Med, 1985 312(4): p. 193–7. [PubMed: 2578212]
40. Seth N, Kaplan R, Bustamante E, Kulkarni C, Subacius H, Rosenthal JE, and Passman R. Clinical Significance of Nonsustained Ventricular Tachycardia on Routine Monitoring of Pacemaker Patients. Pacing Clin Electrophysiol, 2015 38(8): p. 980–8. [PubMed: 25790151]

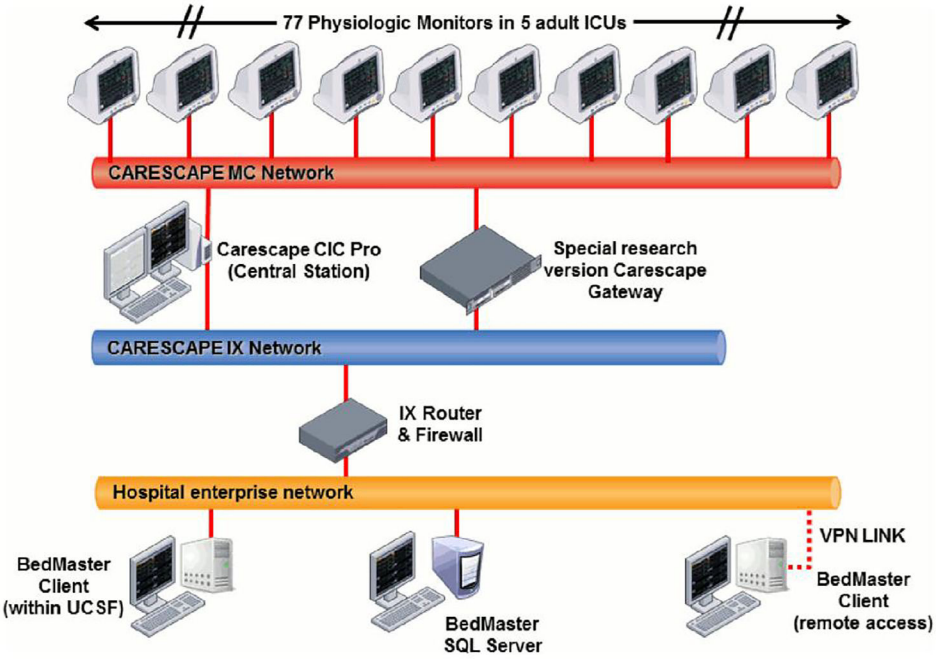

Figure 1.

Hospital infrastructure used to automatically store all physiologic monitor waveform and alarm data.

Figured used with permission. [1]

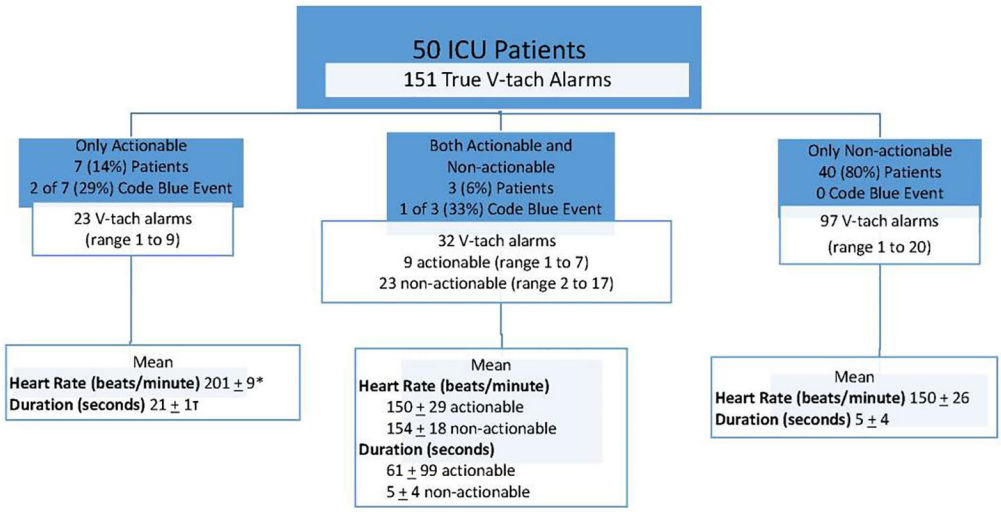

Figure 2.

Shows 50 intensive care unit (ICU) patients with 151 true ventricular tachycardia (V-tach) alarms. The 50 patients were separated into three groups based on whether the V-tach alarms were; (1) actionable only; (2) both actionable and non-actionable, and; (3) non-actionable only.

Table 1.

Definition use for annotation to determine true versus false ventricular tachycardia (V-tach) alarm.(REF)

Ventricular Tachycardia ≥6 consecutive PVCs with rate a ≥100 bpm	**Proof of True Positive:** (any of the following confirms true positive alarm) 1. Simultaneous drop in invasive arterial or pulmonary artery (PA) pressure. 2. Documentation from electronic health record (EHR) of V-tach at same time; standard 12-lead ECG documentation of V-tach read by cardiologist. 3. Atrioventricular (AV) dissociation is evident throughout the wide QRS tachycardia in any ECG lead. 4. V-tach event wide QRS morphology is different than patient's baseline rhythm with bundle branch block (BBB). **Proof of False Positive:** (any of the following confirms false positive alarm) 1. No simultaneous change in invasive arterial or PA pressure (if it is "slow" VT with rate 100–150, there will be less decrease in pressure waveform amplitude). 2. There are QRS complexes with the same R-R intervals as the patient's baseline rhythm evident in any ECG lead throughout the alarm event. 3. Good quality SpO_2 signal has pulsatile waveform that matches rate of underlying baseline rhythm. 4. V-tach alarm duration is > 60 seconds but there is no EHR documentation that it was recognized clinically (syncope, seizure, loss of consciousness, cardiac arrest). 5 Event has the same wide QRS complex morphology in all 7 ECG leads as the patient's baseline rhythm with right or left BBB; additional confirmation if sinus P waves are evident prior to each QRS or the rhythm has no discernable P waves but is randomly irregular indicating atrial fibrillation. 6. Event is due to intermittent ventricular pacing (visible pacer spikes before each wide QRS or QRS in all 7 ECG leads matches a standard "diagnostic" 12-lead ECG acquired during ventricular pacing).

Table 2.

Demographic, clinical and ICU variables for intensive care unit patients (n=460) and those with no true V-tach alarms (n=410), and those with one or more true V-tach alarms (n=50).

Variable	Total Sample n = 460 n (%)	No True V-tach Alarm N = 410 (89%) n (%)	True V-tach Alarms n = 50(11%) n (%)	P-value No True V-tach versus True V-tach
Gender				
- Female	211 (46)	190 (46)	21 (42)	0.561
- Male	249 (54)	220 (54)	29 (58)	
Age year Mean (SD)	60 ± 17	60 ± 17	59 ± 15	0.771
Body Mass Index	28 ± 8	28 ± 8	29 ± 8	0.549
Race				
- Asian	76 (17)	71 (17)	5 (10)	
- Black or African American	35 (8)	29 (7)	6 (12)	
- Native Hawaiian, Pacific Islander	8 (2)	8 (2)	0	0.125
- White	280 (61)	244 (60)	36 (72)	
- Unknown, decline/unable to state	61 (13)	58 (14)	3 (6)	
Ethnicity				
- Not Hispanic or Latino	400 (87)	356 (87)	44 (88)	
- Hispanic or Latino	52 (11)	46 (11)	6 (12)	0.605
- Unknown, decline/unable to state	8 (2)	8 (25)	0	
Intensive Care Unit (ICU) Type				
- Medical-surgical (32 beds)	183 (40)	166 (41)	18 (36)	
- Neurological (29 beds)	195 (42)	182 (44)	13 (26)	0.001
- Cardiac (16 beds)	82 (18)	62 (15)	19 (38)	
Code Blue anytime during ICU admit	13 (2.8)	5 (1.2)	8 (16)	0.001
ECG Features				
- Bundle branch block (right or left)	40 (9)	32(8)	8(16)	0.052
- Ventricular Pacer	16 (4)	10 (2)	6 (12)	0.001
Altered Mental Status	198 (43)	171 (42)	27 (54)	0.097
Mechanical Ventilation	158 (34)	132 (32)	26 (52)	0.005
All Cause Death	27 (7)	26 (6)	8 (16)	0.014

Table 3.

Final diagnosis for intensive care unit patients (n=460) and those with no true V-tach alarms (n=410), and those with one or more true V-tach alarms (n=50).

Primary Discharge Diagnosis	**Total Sample n = 460**	**No True V-tach Alarm N = 410 (89%) n (%)**	**True V-tach Alarms n = 50(11%) n (%)**	**P-value No True V-tach versus True V-tach**	
				Overall p-value	Post-hoc Bonferroni Correction
Cardiac (arrhythmia, heart failure, myocardial infarction)	98 (21%)	78(19)	20 (40)	0.0006	0.0006 *
Medical/Surgical (gastrointestinal, multi-organ failure, sepsis, renal failure, sepsis, trauma)	177 (39%)	163(40)	14 (28)		0.1074
Neurological (stroke, subarachnoid hemorrhaqe)	132 (29%)	122(30)	10 (20)		0.1498
Respiratory (adult respiratory distress syndrome, pneumonia, pulmonary embolismi	53(12%)	47(12)	6(12)		0.9108

* = statistically significant p-value after using the Bonferroni correction for post-hoc analysis.

Table 4.

Shows 50 intensive care unit patients with 151 total ventricular tachycardia (V-tach) alarms, grouped by actionable versus non-actionable. A true V-tach alarm was considered *actionable* if there was a clinical action taken within 15 minutes of its occurrence (i.e., new and/or change of medication, pacemaker, cardioversion or defibrillation, and/or lab test).

Variable	Actionable	Non-actionable	
	Patient as the unit of analysis n = 50 patients		
Alarm Frequencies	n = 10 (20%) patients median = 2 alarms range 1 to 9	n = 40 (80%) patients median = 1 alarms range 1 to 20	
Code Blue Following V-Tach	3(6)	0	0.001*
	Actionable	**Non-actionable**	
	True V-tach alarm as the unit of analysis n = 151 alarms		
	31 (21%) V-tach Alarms	**121 (79%) V-tach Alarms**	**p-value**
Duration (seconds)	56.19 (± 116.87)	4.28 (± 4.09)	0.001
Maximal rate (beats/minute)	188.81 (± 116.83)	150.79 (± 28.26)	0.001

* = Fisher's exact test used - assumption of 5 subjects/cell violated due to small sample size.