PROFILING FALSE ECG CRISIS ALARMS AND POTENTIAL CAUSES

by

Millicent Ogoo

Copyright © Millicent Ogoo 2021

A DNP Project Submitted to the Faculty of the

COLLEGE OF NURSING

In Partial Fulfillment of the Requirements

For the Degree of

DOCTOR OF NURSING PRACTICE

In the Graduate College

THE UNIVERSITY OF ARIZONA

2 0 2 1

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the DNP Project Committee, we certify that we have read the DNP project prepared by Millicent Ogoo, titled Profiling False ECG Alarms in the Medical-Surgical Unit and recommend that it be accepted as fulfilling the DNP project requirement for the Degree of Doctor of Nursing Practice.

Shu Fen Wung
_____ Date: Nov 12, 2021
Shu-Fen Wung, PhD, MS, RN, ACNP, FAHA, FAAN

_____ Date: Nov 12, 2021
Janet Rothers, PhD, MS, MA

_____ Date: Nov 12, 2021
Joseph C. DeBoe, DNP, ACNPC-AG, CCRN

Final approval and acceptance of this DNP project is contingent upon the candidate's submission of the final copies of the DNP project to the Graduate College.

I hereby certify that I have read this DNP project prepared under my direction and recommend that it be accepted as fulfilling the DNP project requirement.

Shu Fen Wung
_____ Date: Nov 12, 2021
Shu-Fen Wung, PhD, MS, RN, ACNP, FAHA, FAAN
DNP Project Committee Chair
College of Nursing

ACKNOWLEDGMENTS

First, I want to thank God for his faithfulness in helping me reach this far in my educational journey. My sincere gratitude to my chair, Dr. Shu-Fen Wung, and my committee members, Dr. Janet Rothers and Dr. Joseph DeBoe, for their mentoring support throughout my DNP Project. I am very grateful to all my committee members for their professional guidance and learning opportunities provided in helping me fulfill my goal as a lifelong learner.

Most importantly, to my chair of this project, Dr. Shu-Fen Wung, thank you for believing in me and my vision and providing your untiring reassurance, support, and kindness throughout this project.

This journey would not have been easy without my family and close friends, who all, in diverse ways, supported me throughout this journey. A special thanks to my son Elvin, who sacrificed so much for me to attain this degree. Thank you, Elvin, for allowing me time away from you while researching and writing this project.

DEDICATION

"With faith, hard work, integrity, and compassion, anything in life is attainable," these were words I constantly heard from my late maternal grandmother, who was also a nurse, and my mother since I was a child. This DNP project is dedicated to my late maternal grandmother, mother, and son, whose support was the driving force behind this outstanding achievement. Their prayers, positive words, and support were vital to the successful completion of my DNP degree.

TABLE OF CONTENTS

TABLE OF CONTENTS – *Continued*

TABLE OF CONTENTS – *Continued*

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Background: The Joint Commission determines that clinical alarm systems are one of the highest patient safety issues. The Emergency Care Research Institute (ECRI) lists alarm overload as the 6th of the top 10 health technology hazards seen in healthcare technology-related issues. Despite the American Heart Association (AHA) recommendations for continuous Electrocardiographic (ECG) monitoring of hospitalized patients for heart rate and rhythm determination to diagnose arrhythmias, false arrhythmia alarms remain an issue for monitoring patients in the intensive care unit.

Purpose: The purpose of this Doctoral of Nursing Practice (DNP) project was to determine the frequency, accuracy, and potential causes of false ECG crisis alarms.

Methods: A retrospective quantitative descriptive study was conducted from an alarm database on a 12-bed adult intensive care unit within a hospital in the Southwest region of the United States.

Results: The majority (95%) of crisis alarms in the intensive care units are false. The study showed high inter-rater reliability in false alarm determination. Out of 471 ECGs reviewed, 22 ECG alarms were true, two ECG alarms were undetermined, and 446 ECG alarms were false. The main non mutually exclusive causes of false alarms were artifacts (n=418, 93.7%), followed by low ECG amplitude (n = 264, 59.2%).

Conclusion: The result of the project showed a high rate of false crisis alarms in the intensive care units. The findings of this project identified a need to develop quality alarm initiatives to decrease false ECG alarms and clinical alarm fatigue. This DNP project focused on evidence-based practice initiatives to address false crisis alarms.

Keywords: "ECG False Alarms," "ECG Alarms," "Alarm Fatigue Healthcare," " Alarm Management

INTRODUCTION

Background Knowledge

Cardiac telemetry monitoring plays a vital role in cardiac rate and rhythm monitoring and diagnosing arrhythmia during a patient's acute hospitalization (Stoltzfus et al., 2019). For hospitals in the United States (US), cardiac telemetry monitoring can save costs within the healthcare system (Stoltzfus et al., 2019). The American Heart Association (AHA) recommends continuous electrocardiographic (ECG) monitoring of hospitalized patients for heart rate and rhythm determination to diagnose arrhythmias, myocardial infarction, and drug-induced prolonged QT interval (Sandau et al., 2017). An ECG is a non-invasive tool that records the electrical signals originating from the myocardium, frequently used to diagnose cardiac disorders (Raj et al., 2018). According to the AHA, there are four grounds for arrhythmia monitoring. First, cardiac monitoring can recognize sudden cardiac arrest, which clinicians can use to treat early defibrillation. Second, cardiac monitoring can identify worsening conditions of arrhythmias, thereby prompting early treatment. Third, cardiac monitoring can help manage arrhythmias such as bradycardia, extreme tachycardia, ventricular tachycardia, ventricular fibrillation, atrial flutter, and asystole. Fourth, cardiac monitoring helps to diagnose arrhythmias to guide therapy (Clifford et al., 2015). Despite ECG monitoring promptly recognizing arrhythmia, 90% of arrhythmia alarms are false (Drew et al., 2014).

The Joint Commission determines the highest priority patient safety issues, including the National Patient Safety Goals (NPSGs) from stakeholders such as healthcare providers within the healthcare system (The Joint Commission, 2020a). As part of the 2021 Hospital National Patient Safety Goals, the NPSGs focus on health care safety problems and solutions to improve patient

safety. The NPSG Goal Six (6) on Clinical Alarm Safety aims to reduce patient harm associated with clinical alarm systems. The NPSG.06.01.01 pursues ways to improve the safety of clinical alarm systems of medical equipment in critical access hospital care settings (The Joint Commission, 2020b).

According to the Association for the Advancement of Medical Instrumentation (AAMI), an organization that supports effective medical technology management and safety, medical alarm systems have been on the top health technology hazard for many years (Association for the Advancement of Medical Instrumentation, 2011). The Emergency Care Research Institute (ECRI) lists alarm overload as the 6th of the top 10 health technology hazards in healthcare technology-related issues (The Emergency Care Research Institute [ECRI], 2020). The Food and Drug Administration (FDA) seeks to protect the public from harm caused by medical devices by encouraging innovations to improve safety, detect safety risks, and keep doctors and patients better informed (Food and Drug Administration [FDA], 2019).

The goal of the 2015 Physio-Net/Computing in Cardiology Challenge, the signature of the Research Resource for Complex Physiologic Signals under the sponsorship of the National Institutes of Health (NIH), also seeks to promote measures on the progression of algorithms to reduce the occurrence of false alarms in the intensive care unit (ICU) (PhysioNet, 2015). The challenge addressed critical false arrhythmia alarms in the ICU by promoting new algorithms to improve alarms' specificity (Clifford et al., 2015). To reduce healthcare professionals' overall notification burden, the Emergency Care Research Institute (ECRI) recommends in their 2020 Special Report: Top 10 Health Technology Hazards for 2020 that healthcare organizations support staff members in using strategies to prevent alarm fatigue (ECRI, 2020).

Significance

False alarms are alarms that are inaccurate replications of the condition shown. False ECG alarms have a great significance on alarm fatigue. Alarm fatigue can cause inevitable patient morbidity and mortality when critical true alarms are ignored by nurses (Ruppel & Funk, 2018). The increase in false alarms can overwhelm hospital staff to the point that they cannot adequately and efficiently interpret alarms (Jacques, 2016). The nurse's cardiac monitoring role includes ensuring that cardiac monitoring leads are securely attached and connected to the patients, and the cardiac alarm parameters are correctly set (Ruppel & Funk, 2018). Nurses are responsible for both the technical and clinical decision-making aspects of cardiac monitoring (Funk et al., 2017). Besides cardiac monitoring, nurses have other vital tasks, ranging from medication administration, admitting, and discharging patients, and responding to alarm notifications. Responding to false alarms can be tedious and disruptive, causing frequent interruptions and multiple clinical multitasking. Thus, nurses are mandated to make tough decisions daily about responding to several alarms going off from different patients or continuing with the tasks at hand, assuming that they do not require their instant attention (Karnik & Bonafide 2015).

The burden of acting on several non-actionable false alarms can drain nursing resources, causing alarm fatigue. Alarm fatigue significantly impacts patient safety, with the worst case resulting in death or severe patient harm (Casey et al., 2018). When nurses are desensitized to alarms, medical errors due to omission, distraction, or inattention can occur (Srinivasa et al., 2017). According to The Joint Commission sentinel event alert in 2013, factors contributing to medical device alarm-related injuries or deaths include alarm-related technical factors and

human-related factors like staff alarm fatigue and insufficient staff training (The Joint Commission, 2013). When the Joint Commission published its first Sentinel Event Alert addressing medical device alarm safety in hospitals, it reported a total of 98 alarm-related events. Out of the 98 alarm-related events, there were 80 deaths, 13 patients had permanent cardiac damage, and five patients had an additional stay in the hospital (The Joint Commission, 2013). The ECRI lists alarm, alert, and notification overload as part of the ten health leading technology hazards for 2020 (ECRI, 2020). The United States Food and Drug Administration (FDA), an agency within the United States Department of Health and Human Services (USDHHS), reported 566 deaths caused by monitoring alarms (FDA, 2011).

Project Setting

This Doctor of Nursing Practice (DNP) project involved an analysis of crisis alarms from an alarm database. The alarm database comprised crisis alarms collected from an ICU in an acute care hospital setting.

Local Problem

ECG monitoring goals range from capturing heart rate and cardiac rhythm to identifying and diagnosing complex arrhythmias, recognizing myocardial ischemia, and documenting and monitoring drug-induced prolonged QT interval (Sandau et al., 2017). The sample of this DNP project was patients admitted to the ICU who have serious health conditions. Monitoring for arrhythmias remains a vital surveillance tool to protect critically ill patients. The ECG monitor is equipped with alarms when a specific parameter (such as heart rate) exceeds a pre-defined range (Clifford et al., 2016). The sound of crisis alarms aims to alert nurses of the need for intervention based on a change in the patient's clinical condition; however, it results in alarm fatigue when

false alarms do occur (Petersen & Costanzo, 2017). False ECG alarms arise when there is no valid factor-generating event, whereas nonactionable alarms are valid events with no clinical significance (Sandau et al., 2017). Many factors often prompt false arrhythmia alarms. These factors can either be technical or patient-related causes that generate alarm signals. Many technical issues occur due to equipment-related glitches such as battery depletion, and patient alarm issues are explicit to the patient's cardiac status, such as arrhythmia (Sandau et al., 2017).

Health care workers, especially nurses, are exposed to an overload of alarms that leads to alarm desensitization, a risk to patient safety (Srinivasa et al., 2017). The 2016 Healthcare Technology Foundation Clinical Alarm Survey supports the notion that alarm fatigue seen by the nursing staff and the monitor technicians are from recurrent false alarms (Healthcare Technology Foundation Clinical Alarm Survey, 2016). Alarm fatigue is related to many false alarms and nonactionable alarms, resulting in the nurse losing trust in the cardiac monitoring system and devaluing the warnings, which can fail to recognize an acute change in the patient's condition (Turmell et al., 2017). Burnout syndrome (BOS) occurs in all healthcare professionals but is significantly more common in nurses working with critically ill patients. BOS progression is related to the unevenness of the employee's characteristics and work-related problems or other organizational matters resulting in decreased effectiveness and poor work performance, directly impacting patient care (Moss, 2016).

Project Aims, Purpose and Objectives

This DNP project aims to improve critically ill patient care outcomes and nursing experience by analyzing crisis alarms collected from patients while on cardiac monitoring in the ICU setting for accuracy and validity of alarms. The alarm dataset contains crisis alarms with

multi-channel ECG tracings from patients in the ICU in a hospital setting. The objectives of this DNP project were to describe the following:

- The interrater reliability in determining the validity of alarms using the alarm annotation protocol by Drew et al.
- The frequency of false ECG crisis alarms; and the frequency of various causes of false ECG alarms.

Findings from this project can guide nurses on how to target false ECG crisis alarms within their care unit to improve clinical ECG alarm management skills and discover practical solutions for false ECG alarms that may enhance inpatient care safety

Study Question

Although alarms on cardiac monitors aim to improve patient safety by alerting clinicians like nurses to certain arrhythmias, these alarms have unexpectedly caused patient safety risk and nurse burnout. Nurses are the end-users of most technology, such as the cardiac monitoring device. How nurses interact with such devices affects the value of the safe patient care they provide. This DNP project's study question was: What are the causes that generate crisis alarms from the cardiac monitors on patients admitted to the ICU? The goal of this project was to determine the frequency of ECG false crisis alarms and the potential causes of these crisis alarms in an ICU. The study's question can inform an appropriate alarm management process, thus improving patient care outcomes and nursing care experience in the ICU.

Theoretical Framework

The purpose of this DNP project is to evaluate frequency, validity, and potential causes for crisis alarms. The Conceptual Framework that guided this project was the Plan-Do-Study-Act

(PDSA) framework. The PDSA is a framework that turns ideas into action and connects learning activities (Langley et al., 2009). The PDSA cycle addresses quality of care problems and establishes evidence-based solutions (Langley et al., 2009).

Figure 1

Plan-Do-Study-Act (PDSA) Cycle

Langley, G. J., Moen, R. D., Nolan, K. M., Nolan, T. W., Normal, C. L., & Provost, L. P. (2009). The improvement guide: A practical approach to enhancing organizational performance (2nd ed.). San Francisco, CA: Jossey-Bass

Plan-Do-Study-Act (PDSA) Cycle Concepts

Structure

The PDSA framework help individuals and teams test, adapt, and implement changes to improve patient care quality. Per Deming (1988), the father of quality control, the PDSA cycle is an effective methodology designed to test and adapt changes. Leis and Shojania (2016) describe

the PDSA cycle as an appropriate guide to assess and implement change in healthcare settings. The PDSA cycle allows for iterative testing of changes to improve the quality of systems. The objective of the PDSA cycle is to develop a change. The principal investigator accessed the alarm data set and analyzed the ECG waveform to determine its structure. Below are the four parts of the PDSA cycle and how they can be applied for this DNP project.

Plan

The "Plan" is the first phase to develop the process, which is essential for a successful test cycle (Provost & Murray, 2011). There is an increase in clinically insignificant alarms in clinical units in the hospital care settings. The burden of crisis alarms was investigated to provide unit-specific interventions on reducing crisis alarms (Srinivasa et al., 2017). This DNP project's long-term goal is to improve patient care outcomes and nurses' clinical alarm management experience. During the planning phase, a prediction of the outcome is established. The principal investigator accessed the alarm dataset to determine the presence of false ECG crisis alarms and the potential causes. The frequency, type of arrhythmia, and causes of the false ECG crisis alarms can serve as baseline information to guide the changes to be made. The results obtained from this DNP project can provide information for the changes required to address clinical alarm mismanagement and false ECG crisis alarms.

Do

The "Do" is the cycle phase where the plan is carried out, and the changes are tested (Provost & Murray, 2011). In this phase, the plan is implemented using the information obtained from the planning phase. The data collected were analyzed to uncover the frequency, presence,

and causes of false alarms. The investigator analyzed data and documented the number of true and false alarms, the arrhythmias present, and the potential reasons for the false ECG alarms.

Study

The "Study" phase compares the data and analyzes the results (Langley et al., 2009). In this phase, a real-world application of constructing, interpreting, and using run charts for improvement initiatives is carried out (McQuillan et al., 2016). During this phase, the goal was to determine whether the expected outcome was attained or not ("Managing Alarms in Acute Care Across the Life Span: Electrocardiography and Pulse Oximetry," 2018). After data analysis completion, recommendations for future work to be used by nurses working with patient cardiac monitors would be provided.

Act

The "Act" phase takes logically based action founded on what was learned to refine the cycle (Langley et al., 2009). The long-term goal of this DNP project is to improve clinical alarm management. This phase may provide answers to the best possible alarm management strategy to reduce the number of false ECG crisis alarms. The final stage of the PDSA cycle, the Act phase, allows the investigator to evaluate the final result and make flexible changes to achieve the desired outcome. This phase requires presenting the data to the key stakeholders to take the necessary steps to keep, modify, revise, or reject the process and then propose the next change in the PDSA cycle (McQuillan et al., 2016). The goal of this DNP project was to validate the rate of crisis alarms and recommend interventions to tackle false crisis alarms. The process of testing the effect of alarm management interventions may or may not require several PDSA cycles. Hence, the iterative process that surrounds the PDSA cycle demonstrates the importance of

ground-level qualitative feedback, real-time data collection, and why "the people who do the work must change the work" (McQuillan et al., 2016). Using data over time can provide a better understanding of the issues surrounding false ECG alarms.

Literature Synthesis

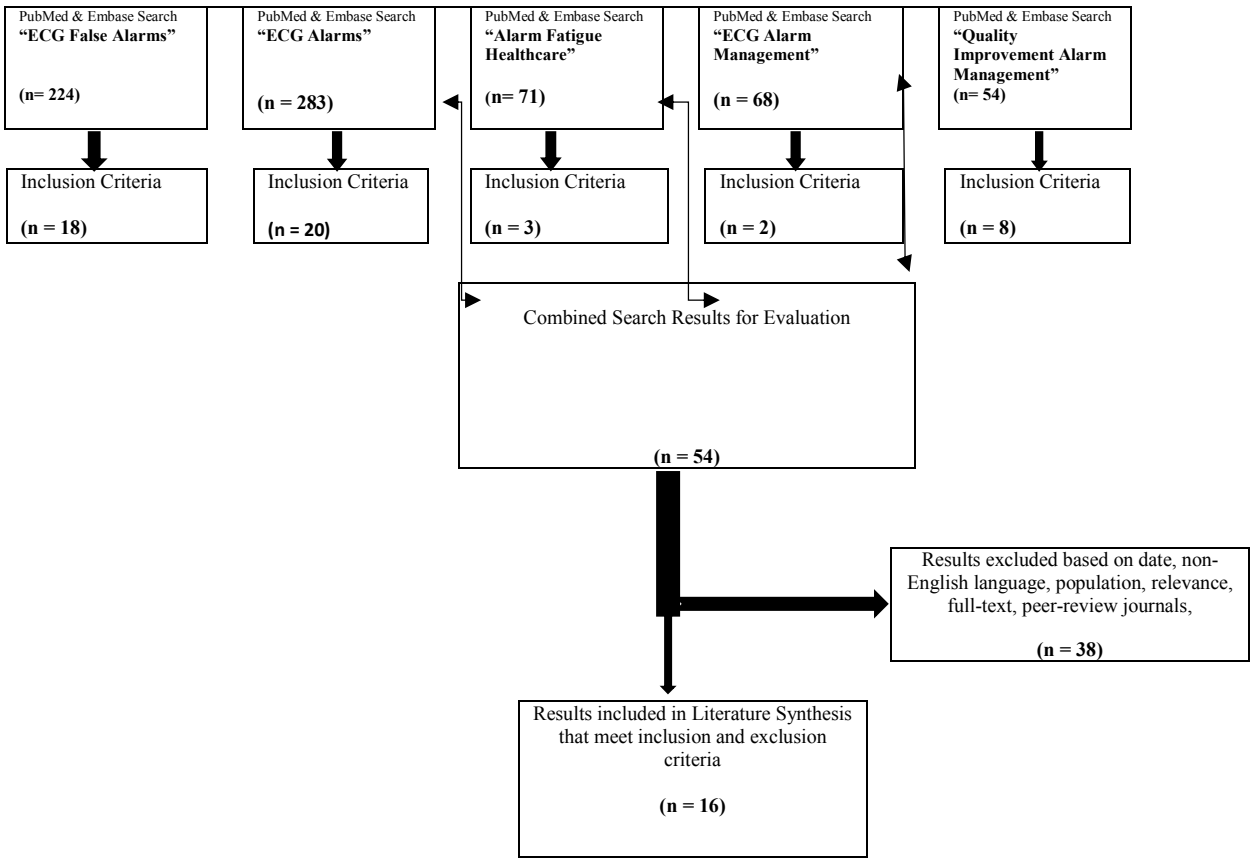
Evidence Search

For this DNP project, a literature search regarding false cardiac arrhythmia alarms was conducted to determine the impact on patient care outcomes and nursing staff. The first step of the literature review was to review the presence of false ECG alarms. The search engines utilized included: PubMed, EBSCO HOST, Embase, Web of Sciences databases, hand-searching bibliographies, Google Scholar, and Cumulative Index to Nursing and Allied Health Literature (CINAHL). Among these databases reviewed, two databases were used, PubMed and Embase. The keywords used in the literature search included: "ECG False Alarms," "ECG Alarms," "Alarm Fatigue Healthcare," "ECG Alarm Management," and "Quality Improvement Alarm Management." Each article's inclusion criteria were studies or quality improvement projects that looked at the causes and effects of false ECG alarms. These were limited to citations in English, published between January 2015 to December 2020, and conducted in a hospital setting. The exclusion criteria for each article searched were limited to non-English language, population, relevance, full-text, peer-review journals. Additional searches were also carried out on several patient safety sites such as the Association for the Advancement of Medical Instrumentation, PhysioNet, The Critical Care Societies Collaborative, The Emergency Care Research Institute, Healthcare Technology Foundation, Food and Drug Administration, and the Joint Commission on Accreditation of Healthcare Organizations (JCAHO). Sixteen articles were clinically relevant

to the study for analysis utilizing the level of evidence. See Table 1 for the flow chart on the literature review.

Table 1

Evidence Search Flow Diagram



Comprehensive Appraisal of Evidence

The purpose of the search process was to conduct a comprehensive review of the impact of false cardiac arrhythmia alarms on nurses and patient safety. The best available evidence was systematically examined for clinical relevance on crisis alarm to provide the best available clinical alarm management information. Synthesizing the literature review requires linking ideas and themes needed to answer the study question in this project (Fries-Gaither, 2010). For

synthesis, the body of evidence revealed both aggravating and mitigating causes of false alarms grouped under the following themes:

- Signal Analysis
- Interventions Used to Reduce False and Non-Actionable Alarms
- Alarm Fatigue

Nurses' Training on Alarm Management (See Table 1 for the synthesis of evidence)

Signal Analysis

Based on the literature, false ECG alarms are caused by low QRS amplitudes.

Low QRS Amplitudes

In a study by Pelter et al. (2016), the researchers examined 12-lead ECGs on 82 ICU patients for the presence of one or more false-positive asystole alarms. The study assessed the impact of low amplitude QRS complexes on false-positive asystole during the patient's continuous 12-lead ECG monitoring. Following a review of the ECGs using a software algorithm for QRS detection, low QRS amplitude was seen to cause the false ECG alarms. Low QRS amplitude is when a unidirectional (only positive and negative) QRS did not exceed 5mm in two of the four leads I, II, III, and V1 used for QRS detection. Of the 82 patients reviewed, 45 (55%) of the patient's 12-lead ECG had low amplitude QRS. The study noted that more than half of the low amplitude QRSs measurement patients had false asystole alarms. The study further suggests that obtaining a 12-lead ECG on patients admitted to the hospital and reviewing for low amplitude QRSs might help nurses identify patients at risk for false-positive asystole alarms.

Interventions Used to Reduce False and Non-Actionable Alarms

Alarm Customization

Srinivasa et al. (2017) studied interventions addressing alarm customization as part of a quality improvement project. The quality improvement project used the Model for Improvement Framework (MFI), an evidence-based approach to identify the need to reduce cardiac telemetry alarm fatigue, and the Plan Do Study Act (PDSA) cycles to test a change at each stage. The study used alarm tracking software to capture telemetry alarms. Forty percent of the insignificant clinical alarms captured were Premature Ventricular Contractions (PVCs) alarms, which produced a noise level of 58.49 dB. The study results showed a reduction of 54 % of alarm rates and an average noise reduction to 2.3 dB. Hence changing alarm parameters can help reduce the noise level to optimize patient care. This study provided datasets for use by a multidisciplinary team consisting of nursing, engineers, and providers opportunities for an evidenced-based approach to improve cardiac telemetry alarm fatigue. The study theorized that Premature Ventricular Contractions (PVCs) alarms, which make up a large percentage of alarms on the floor, have proven to be non-actionable. This project further validated those changes to alarm parameters can help reduce the noise level to optimize patient care. Also, a less noisy environment can allow nurses to become sensitized to alarm noise to stay focused on clinical tasks. Alarm customization on a cardiac monitoring device helps nurses monitor their patients effectively without compromising patient safety (Srinivasa et al., 2017).

Factors Affecting Alarm Customization

In a qualitative mixed-methods study by Ruppel et al. (2019), the researchers interviewed 27 ICU nurses on alarms' customization knowledge. Four themes, including unit alarm culture

and context, nursing characteristics, drive to customize alarms, and knowledge of customization, were explored during this study. The study showed that the unit's alarm culture could hinder nurses' drive to practice alarm customization preparation as part of patient assessment and evaluation of customizing cardiac monitoring alarm settings. The study concluded that nurses customize physiologic monitor alarms based on their level of technical and clinical expertise, the alarm culture on their clinical unit, and colleagues' and patients' responses to alarms (Ruppel et al., 2019).

Default Setting Changes

A retrospective quality improvement project at a busy Emergency Room (ER) tertial-care hospital in Hawaii from December 2016 to March 2019 by Fujita and Choi (2020). The study included a review of alarm triggers from a cardiac monitor between a pre-and post-implementation protocol. This DNP project aimed to show the need to customize monitor alarm default settings as a protocol to help reduce false cardiac monitor alarms in the ER. The project findings showed a reduction of false alarms following an intervention to change the default cardiac monitoring setting from a hospital-wide preset to an ER-specific setting. This reduction in false alarms helped create a protocol for staff to customize alarm settings based on clinical unit-specific (Fujita & Choi, 2020).

In Pelter et al. (2020), a secondary analysis of Ventricular Tachycardia (V-Tach) found of 460 ICU patients, 50 patients had V-Tach events. Forty patients had 97 nonactionable V-Tach events, three patients had 32 actionable and nonactionable events, and seven patients had 23 actionable alarms. Still, none of these patients required clinical intervention related to the V-tach events. The study showed that the current hospital cardiac monitoring default setting set at ≥ six

consecutive wide QRS complexes > 100 beats/minute is too sensitive, which causes false alarms. The study also noted that the patients with V-tach events had a shorter timeframe at 5 seconds despite an increased heart rate of 150 beats per minute. This finding suggests that adjusting cardiac monitors' default settings to > 130 beats/minute and duration of > 20 seconds might improve recognition of actionable V-tach. An algorithm-based approach was proposed for hospitals to adjust preset default alarm setting parameters as interventions to help reduce false alarm-related events (Pelter et al., 2020).

Skin Preparation and Electrode Changes

As part of a quality improvement (QI)project, implementing a bundle of interventions like alarm manipulation and skin preparation for electrode placements was studied. Sendelback et al. (2015) performed a QI project in a 16-bed cardiovascular care unit (CCU) using a bundled set of interventions. The interventions included daily ECG electrode changes, disposable ECG leads, skin preparation, alarm customization, and removal of duplicate alarms. After implementing these interventions, the study revealed an 80% to 90% reduction in ECG alarms in the CCU. Walsh-Irwin and Jurgens (2015) also conducted a prospective descriptive study to test the effect of proper skin preparation and ECG lead placement as interventions that reduce alarm frequency. The study showed that out of the 15 sampled patients, daily electrode changes and skin preparation reduced alarms caused by artifacts compared to the same population studied in a 24-hour timeframe without any skin preparation interventions or electrode changes (Walsh-Irwin & Jurgens, 2015). Shue McGuffin and Ortiz (2019) conducted a comparative quantitative study on a 36-bed inpatient telemetry unit on the effectiveness of how daily electrode changes can decrease nuisance alarms. Before the data collection, nurses changed patient electrodes every 72

hours at various times of the day per hospital policy. Following an intervention of daily electrode changes by staff, the study comparison determined that the unit experienced a reduction in ECG crisis alarm frequency due to ECG electrode changes.

Alarm Fatigue

In a study by Tscholl et al. (2019), the researchers interviewed 120 anesthesiologists about their cardiac monitoring experience with patients in a hospital. This mixed-method research study aimed to provide insights on problems seen with patients on cardiac monitors. This study's quantitative part looked at three main daily issues: hardware problems (cable entanglements and worn connectors), human factors (fatigue and distractors), and systemic factors (insufficient standardization between manufacturers). The qualitative part of the study focused on how anesthesiologists shared their views on how they are mentally and physically affected by cardiac monitoring warning alarms, either caused by human error or hardware problems while monitoring patients on a cardiac monitoring device. They also noted that inadequate standardization between manufacturers and device equipment created hardware issues such as defective cables and connectors. The study findings confirmed existing patient monitoring issues related to alarms, artifacts, and information overload. The study results showed that a well-designed cardiac monitoring device should prevent false positive alarms on patients on cardiac monitors (Tscholl et al., 2019).

Peterson and Costanzo (2017) conducted a QI project to evaluate the nurses' perceptions of alarm fatigue. The study was a qualitative survey comprising 31 nurses that work in critical care. The nurse's perception response from the survey highlighted nine alarm issues that addressed the following themes: adverse events, monitor watchers, alarm initiatives, and

technological solutions. The most perceived problem of alarm fatigue reported in the survey was inadequate staffing. The second issue was a lack of understanding of an alarm's priority and subsequent issues, including alarm setting, alarm source, alarm noise, and lack of education on alarm systems. This project's findings support the need for an improved clinical alarm management system to help reduce false ECG alarms and their impact of alarm fatigue on nurses (Petersen & Costanzo, 2017).

Nguyen et al. (2020) conducted a retrospective secondary analysis of 461 ICU patients on continuous ECG bedside monitoring in a prospective observational study. Seventy-one (15%) patients had at least one arrhythmia alarm and one false arrhythmia alarm from the study. These patients produced 10,699 arrhythmia alarms, 1,348 (13%) were true arrhythmias, and 9,351 (87%) were false arrhythmias. Among the six types of arrhythmias reviewed, Accelerated Ventricular Rhythm, Ventricular Tachycardia, Pause, Ventricular Bradycardia, Asystole, and Ventricular Fibrillation received the highest false alarms (94%). When these arrhythmias occur, it triggers a crisis-level alarm, and it continuously sounds until a staff member manually acknowledges it. This study brings forth the impact of false alarms and how they contribute to the 'cry-wolf phenomenon.' The *cry wolf phenomenon* results from alarm fatigue. This phenomenon is when nurses do not see the need to respond to alarms due to several responses to false ECG alarms; thereby, true alarms are missed, which is a patient safety concern (Nguyen et al., 2020).

Nurses' Training on Alarm Management

Poncette et al. (2019) conducted a qualitative study on intensive care nurses' statements on patient monitoring systems. The study emphasized nurses' lack of trend analysis on the use of

novel alarm technology devices. Nurses noted that usability factors played a role in getting acclimated with using digital health technology devices to aid clinical decision support systems. The nurses interviewed provided candid feedback on implementing a sustainable digital health technology to improve medical device usability, reduce alarm fatigue, and promote improved care standards in medicine. This study's findings showed a need to enhance the nurse's knowledge of cardiac monitoring device usability. End-users like nurses should be part of the implementation process of digital health technology.

Nurses require adequate knowledge to carry out effective patient cardiac monitoring (Funk et al., 2017). The Pulse Use of the Latest Standards of Electrocardiography (PULSE) trial conducted a randomized clinical trial that investigated nurses' experience on ECG monitoring. During the trial, nurses' knowledge of quality care related to ECG monitoring was measured. The PULSE trial result showed that providing educational intervention on ECG monitoring practice standards to nurses improved nurses' knowledge on ECG monitoring up to 15 months following the intervention. The education interventions include accurate electrode placement, accurate rhythm interpretation, appropriate monitoring, and ST-segment monitoring. The clinical trial showed that improving nurses' knowledge of ECG monitoring following educational intervention yielded effective patient arrhythmia monitoring and quality patient care (Funk et al., 2017).

In a stud by Yue et al. (2017), a systemic review of experimental studies conducted between 2005 and 2015 aimed to investigate educational strategies' effectiveness on managing clinical alarms among nurses. In addressing human factor-related challenges with alarm management, it is crucial to pay close attention to the end-users like nurses who operate these

clinical devices. Nurses are the end-users of cardiac monitors; hence they should be equipped with how to use clinical devices used for patient care. The review included five studies that provided nursing education interventions on alarm signal detection, alarm learning, and the use of Spencer and Foss (2009) clinical alarm safety learning activities. The study showed that education interventions could improve education effectiveness on clinical alarm response and management.

Crimlisk et al. (2015) provided a cardiac monitoring educational activity to nurses during hospital orientation. As part of the educational strategy intervention on cardiac monitoring, a two-year study was conducted on all nurses working in the medical-surgical areas. The educational activities included a competency-based telemetry tool kit provided to the nurses during orientation, followed by a 12-hour dysrhythmia class. After the course, a competency-based test was done with a passing score of 90% or higher before nurses would keep their staff nurse position. This study showed an increased staff knowledge in ECG monitoring with a passing grade of 90% or higher in the dysrhythmia test. The study also noted increased staff flexibility and hospital-wide implementation of dysrhythmia competency for all cardiac monitoring units.

Strengths of Evidence

Methods to tackle false alarms in the existing literature can be grouped into two parts. The first part is the technical aspect surrounding issues related to the cardiac monitoring device. The second part is the clinical aspect related to end-users of cardiac monitoring. For the technical aspect, good signal quality is essential to help distinguish false from true alarms. For the clinical part, adequate clinical alarm training for nurses on lead placement, ideal default parameter

setting, and improved organizational policies are efforts that can address issues with ECG false alarms (Zong et al., 2016).

False alarms can be costly as alarm fatigue has the potential to cause patient harm. However, clinical nurses are frontline to address these complex problems seen with alarm-related events (Karnik & Bonafide 2015). A quality improvement study by Sendelbach et al. (2015) and Whalen et al. (2014) has indicated that customization of cardiac monitor alarms can reduce false alarms and impact patient care and end-users. For example, Fujita and Choi (2020) showed that alarm customization specific to clinical units backed up by staff education on alarm customization created protocols specific to clinical alarm management in these units. The bundled skin preparation interventions and daily electrode changes on patients admitted to a telemetry unit have been shown to decrease alarms (Walsh-Irwin & Jurgens, 2015). In a systematic review conducted by Yue et al. (2017), various factors, including nurse demographics, nurse participation, nurse workload, and alarm characteristics, can influence nurse training effectiveness on clinical alarms. Overall, nurses' education on clinical alarm management was a strength noted when profiling ECG false alarms.

Weaknesses of Evidence

In the study by Pelter et al. (2016), a false-positive asystole alarm was noted on 12-lead ECGs. However, most of the studies reviewed did not specify the ECG leads used for false alarm detection. In Fujita and Choi (2020), though the need to customize alarms was based on the clinical unit to decrease the number of false alarms, there were no reports of change in patient condition or delay in care resulting in death due to adjusting the default setting. In the study, Sendelback et al. (2015), Walsh-Irwin and Jurgens (2015), and Shue McGuffin and Ortiz (2019)

showed a reduction in alarms from daily ECG lead changes. These studies did not address if ECG lead change intervention is feasible for patients with skin breakdown or other factors limiting access to the chest wall for proper lead placement. This study also did not address the impact of daily skin friction and pain incurred from daily ECG lead removal, putting a patient at risk for skin breakdown and increased risk for infection and hospital-acquired conditions leading to increased healthcare costs.

It is imperative to develop alarm limit profiles for patient groups based on diagnosis or age and modify the alarm settings on the bedside monitor tailored by patient groups (Managing Alarms in Acute Care Across the Life Span: Electrocardiography and Pulse Oximetry, 2018). In Yue et al. (2017), though nurses' education on the clinical alarm is vital, very little information was provided on whether classroom learning, or clinical setting effectively teaches nurses on clinical alarm management. The role of industry players like manufacturers and engineers on medical device usability can help in the clinical alarm management process for digital transformation in the clinical setting (Poncette et al., 2019).

Gaps and Limitations

Though several ECG monitoring leads are used to recognize rhythm or arrhythmia, the standard 12 lead ECG is vastly used. For example, unique leads enhance the atrial activity used in arrhythmia analysis and atrial repolarization assessment (Francis, 2016). For instance, Aboukhalil et al. (2008) proposed using arterial blood pressure (ABP) waveforms to suppress false critical ECG alarms. Similarly, Zong et al. (2016) suggested using waveform features of ABP or photoplethysmogram (PPG) signals to reduce false arrhythmias. Though algorithms

using ABP, and PPG can help address ECG false alarms, especially in the ICU, they are still in the developmental stage

Though Ruppel et al. (2019) and Fujita and Choi (2020) conducted studies that showed the effectiveness of customizing alarms in reducing false alarms, there is still a gap in customizing alarms for specific patient populations or individual patients. Ruppel et al. (2018) cited that nurses are not adequately trained to customize alarms. The article further noted that is no effective protocol for nurse-driven ECG customization. There is still more research needed on workflow analysis that reviews the alarm setting management process.

The gap in nurses customizing alarms suggests that nurses should no longer accept preset default alarm settings, and the alarm settings should be assessed individualized for the patient (Turmell et al., 2017). There is still a lack of information on the key determinants that focus on the patient in customizing the device alarm settings. In ensuring patient safety in clinical alarm management, the key focus should not be on the cardiac device and false alarms alone, but a shifting focus towards optimal patient-centered care (Jacques, 2016). In optimizing safe patient-centered care, critical emphasis on getting the alarm to the right patient, right timing, and right clinical setting should address adverse alarm events. Though various remedies for tackling false clinical alarms have been studied, studies on hospital leadership readiness towards embracing strategies to improve clinical alarm to reduce alarm fatigue and improve patient outcomes still need to be explored (Appendix C).

METHODS

The purpose of this DNP project was to analyze the real-time ECG waveforms for the accuracy of crisis alarms collected from an ICU. The objective of this DNP project was to gain an understanding of false crisis alarm identification to improve clinical alarm management.

Project Design

This project used a retrospective descriptive design to profile the type and frequency of true and false crisis alarms and potential root causes of false alarms using an existing alarm dataset. The setting was a 12-bed adult ICU within a medical center in the southwest region of the US. The population was adult patients treated in this ICU with complex medical conditions, cardiac disorders, and general post-operative surgery.

Model for Implementation

Instruments and Procedures

Description of the Alarm Dataset

The dataset comprised 471 alarms that were generated from patients treated in a 12-bed adult ICU. Each of the 12 ICU beds was furnished with a Solar 8000i bedside monitor manufactured by GE Healthcare, Milwaukee, WI. The bedside monitor can concurrently display data from multiple ECG channels and allowed exporting data to an external server for analysis. The Solar 8000i bedside monitor was equipped with ECG leads for QRS detection. The morphology for QRS detection required a positive (above the baseline) or negative (below baseline) net direction of the QRS complex. The QRS complex or ventricular complex denotes the ventricles' activation, and the QRS duration is the time interval from the onset to the end of the QRS complex. The QRS complex morphology depended on the lead and the clinical

response from patients with a cardiac health condition. The crisis alarms from the bedside monitor manufacturer included the following arrhythmias: asystole, ventricular fibrillation, ventricular tachycardia, and ventricular bradycardia. These life-threatening arrhythmia events were defined as follows: (ECG & Echo Learning, 2008; Clifford et al., 2016).

Asystole. No atrial or ventricular activation for four seconds or more.

Ventricular Fibrillation. A rapid irregular waveform with a variety of morphology and amplitude with no QRS complex seen for at least four seconds.

Ventricular Tachycardia. More than three consecutive ventricular beats at a heart rate of 100 to 250 beats per minute with a wide QRS complex or QRS duration > 0.12 seconds for 2.4 seconds.

Ventricular Bradycardia. Fewer than five ventricular beats at a heart rate of 40 beats per minute or less within six seconds.

Alarm Classification

The monitor's alarm structure is divided into two classifications: patient status and system status alarms. Patient status alarms are prioritized into three levels: crisis, warning, and advisory alarms. The crisis alarms have the highest priority and include arrhythmias such as asystole, ventricular fibrillation, ventricular tachycardia, and ventricular bradycardia, and they are considered the highest priority. The crisis alarms may be triggered by a life-threatening event which produce an audible sound that beeps three times, and the user must silence it.

Alarm Data Collection

The annotators analyzed the retrospective data of each crisis alarm containing multi-channel ECG waveforms from bedside physiologic monitors on all consecutive patients retrieved

from the alarm dataset. The multi-channel ECG tracings includes I, II, III, and V leads. The de-identified physiological waveforms of crisis alarms were made accessible. Each alarm had the waveforms and the alarms interpreted by the monitor.

Crisis Alarm Annotation

Three advanced practice nurses annotated the ECG arrhythmia alarms. The first annotator was the principal investigator, a master prepared hospitalist nurse practitioner, and has completed an elective course on cardiac rhythm analysis at the University of Arizona. The second annotator, Dr. DeBoe, a doctoral-prepared Advanced Practice Nursing-Adult Gerontology Acute Care Nurse Practitioner with clinical experience in cardiology. The third annotator, Dr. Wung, the database developer, is a PhD prepared Acute Care Nurse Practitioner (ACNP) with more than 20 years of clinical research experience in cardiovascular and cardiac monitoring. The first two annotators independently recorded decisions regarding the validity of crisis alarm. The principal investigator compared these results. For cases in which there was disagreement, the third annotator provided a final judgment.

Alarm Validity and Identification of True versus False Alarms

To make their judgments, annotators visually inspected the multi-channel ECGs and determined whether alarms were valid or false. The heart rate from each alarm was verified using ECG waveforms by measuring the RR intervals. The alarm annotation protocol by Drew et al., 2014 was used to guide the definitions of alarm and the criteria used for judging whether the four alarms were true or false. See Appendix B for the Alarm Annotation Protocol.

Ideally, if an alarm truly reflected the underlying patient or system event, annotators judged this to be a valid alarm. Conversely, if the alarm did not truly reflect the underlying event,

this was deemed a false alarm. For example, if an alarm signaled ventricular tachycardia, but the accurate rhythm was normal sinus rhythm, this was identified as a false alarm. For the first step of this project, the level of agreement in the identification of valid versus false ECG alarms between the first two annotators was described. Once the validity of true versus false alarms were established, the frequency and root causes of false alarms were determined

Consent and Ethical Considerations

For this project, an application was sought for ethical approval by the Institutional Review Board (IRB) of the University of Arizona before a retrospective review was performed. The IRB at the University of Arizona determined that human subjects review was not required for this project (Appendix A).

Statistical Analysis

The first project objective was to determine the interrater reliability between two advanced practice nurses in judging the validity of alarms. Cohen's kappa (κ) is a measurement of the agreement for categorical variables that consider both the actual and chance agreement and was used to assess initial interrater reliability (McHugh, 2012). To calculate Cohen's Kappa, the investigator first created and presented a table of frequencies of agreement (the number of alarms deemed true by both advanced practice nurses and false by both advanced practice nurses) and disagreement (the number of alarms considered true by the first advanced practice nurse and false by the second advanced practice nurse, and vice versa).

For the second objective, disagreements in alarms annotated was finalized by the initial database developer, Dr. Wung. The number of false ECG alarms were described in terms of absolute and relative frequencies. The third objective was to describe the frequencies of

identified causes of false ECG alarms. These were also presented as absolute and relative frequencies. Cohen's kappa (κ) was used to measure the percentage agreement for categorical data to determine each annotator's frequency of true and false alarms. Descriptive statistics were used to summarize the number of false ECG alarms and the potential causes of false ECG alarms.

RESULTS

This DNP project aimed to determine the validity of alarms and the frequency of false ECG crisis alarms, and the various causes of false ECG alarms. Under this aim, three outcomes became apparent that answered the two project objectives. The first outcome calculated the inter-rater reliability to determine the validity of alarms. The second outcome determined the frequency of false ECG crisis alarms and the various causes of false ECG alarms. Two annotators reviewed the project's multi-channel ECGs, who judged whether the ECG alarms were true or false. Cohen's kappa statistics (κ) determined the first outcome of interest, which measured a percentage agreement among the annotators. The second outcome of interest determined the frequency of false alarms and the triggers that generated crisis alarms from the cardiac monitors. In two cases, there were disagreements in determining the alarms being false; a percentage of the causes of false alarms was calculated. The two outcomes from this project provided answers concerning the causes that generate crisis alarms from the cardiac monitors on patients admitted to the ICU.

Sample

The sample for this project included a retrospective review of an alarm database that contained 471 ECG strips from 12 adult patients in an ICU within a medical center in the

southwest region of the United States. In this alarm database, alarm type, heart rate, and multi-channel ECG tracings (I, II, III, & V leads) from cardiac monitoring were recorded from consecutive adult patients in the ICU. These adult patients had complex acute medical conditions, cardiac disorders, and post-operative surgery.

Variables

De-identified data files that contained alarm type, heart rate, and ECG signals were available following institutional human subject approval. The multi-channel ECGs and associated alarms were further analyzed to determine whether the ECG alarms fit into true, false, or undetermined categories and to calculate true heart rate. When an alarm was determined to be false, potential causes for the false alarms were described.

Study Objectives

Project Objective 1

The analysis of the ECG tracings and accuracy of arrhythmia interpretation were guided by Drew et al. (2014). Two annotators independently reviewed 471 ECG alarms. When there was disagreement, a third annotator reviewed the cases and determined the status of the alarm. As shown in Table 2, there was one case for which a third annotator determined that a disputed alarm was a true alarm. In two cases, the ECGs were indeterminate by either or both reviewers. Indeterminate cases were not included in the kappa analysis below, for which the denominator is n=469.

Table 2

Alarm Interpretation Disagreement or Undetermined

Annotator 1	Annotator 2	Annotator 3	Count
True	False	True	1
True	Undetermined	Undetermined	1
Undetermined	Undetermined	Undetermined	1

The agreement between annotators is shown in table 3. Table 3 provides evidence of the agreement between annotators. Both annotators agreed that 22 alarms were true, and 446 alarms were false. Only one ECG was determined to be true alarm by Annotator 1 but determined to be false by Annotator 2.

The degrees of the agreement were determined by cross tabulating the results of the two annotators. The percentage of agreement was 99.79% ((468/469)*100). Cohen's kappa considers the possibility that raters can essentially guess on at least some variables due to uncertainty was calculated to be 0.98 (McHugh, 2012). Both calculations indicated an almost perfect level of agreement between annotators.

Table 3

Calculation of Percentage Agreement Between Two Independent Annotators

Annotator 1	Annotator 2	Frequency and Percentage (%)
True	True	22 (4.7%)
False	False	446 (95%)
True	False	1 (0.21%) (Determined to be true by the third annotator)
False	True	0 (0%) (Determined to be true, an undetermined rhythm by the third annotator)

The calculated percentage agreement between Annotator 1 and Annotator 2. In table 4, the first two columns in the matrix contain each rater's true or false alarms, and the last column shows the frequency and percentage agreement.

Project Objective 2

The goal of this objective was to determine the frequency of false ECG alarms and the potential causes. The frequency and causes of false ECG alarms are shown in Tables 3 and 4. There was a total of 11 (50%) ventricular tachycardia alarms and 11 (50%) true asystole alarms. As shown in Table 4, the numerator determined the frequency rate of false ECG alarms, and Table 4 also depicts the two alarms in which disagreements occurred. The characteristics of the two cases. When disagreement occurred, the characteristics of the cases included results that were considered undeterminable by at least one reviewer. The calculated false alarm rate included the total agreement from both raters (446) added to the two undetermined rhythms divided by the total number of ECGs reviewed. The calculated false alarm rate was 0.95 (446+2 = 448/471).

Causes of False Alarms

When determined to be false, each alarm was reviewed for potential causes, as shown in Table 4. The percentage of each cause of false ECG alarms was calculated by dividing the

frequency of each cause by the number of total false alarms (n = 446). Several ECG alarms annotated had more than one ECG anomalies. The potential causes of the false alarms noted in this study included two unanalyzable ECGs, which were undetermined rhythm, followed by a total of 418 artifacts, including motion, muscle, wandering baseline, intermittent signal, lead failure, and AC interference, and 264 low ECG amplitudes.

Table 4

Potential Causes of False Alarms

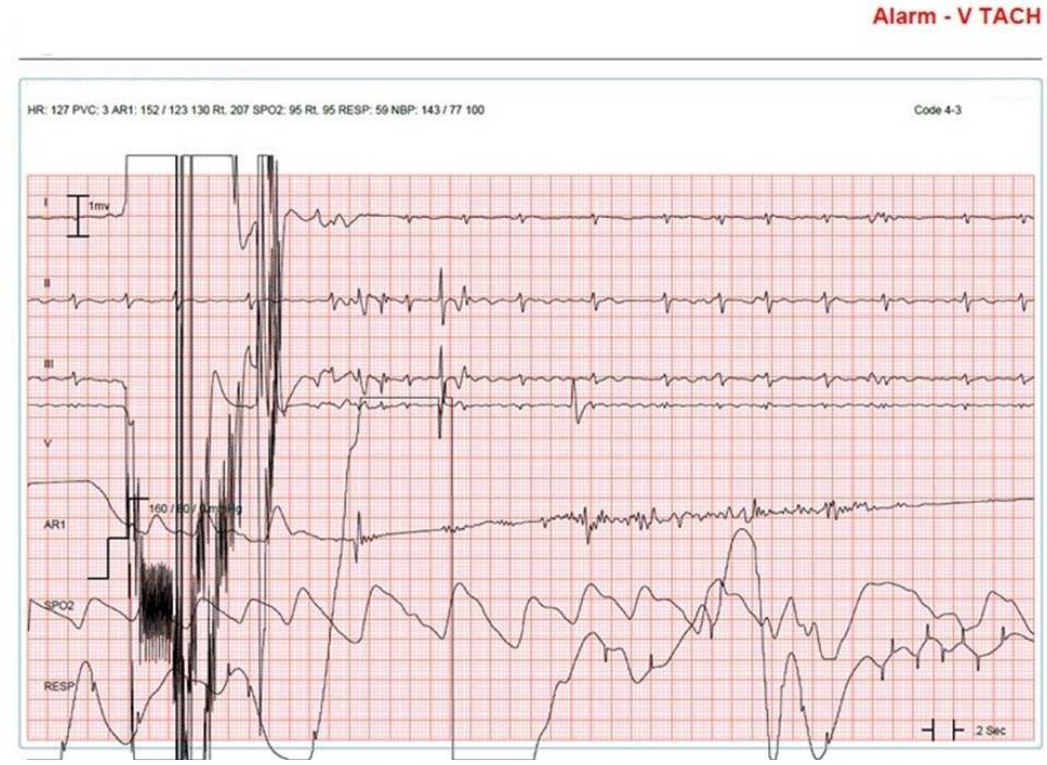
Cause	Count/(%)
Poor readout/Signal as defined by an unanalyzable rhythm that may be due to poor signal quality	2 (**0.45%)**
Artifacts (Motion, Muscle, Baseline Wanders, Intermittent Signal, Lead Failure, and AC Interference)	418 (**93.7%)**
Low ECG Amplitude	264 (**59.2%)**

The percentages of causes of false alarms as determined by dividing the count by the total number of false alarms (446).

Some false alarms had multiple potential causes, thus the added percentages exceeded 100%. ECG artifacts, as seen in Figure 2, are non-physiologic causes that interfere the recordings of cardiac electrical activity (Sivaraks & Ratanamahatana, 2015).

Figure 2

An Example of ECG Artifacts



Artifacts contribute to this false ventricular tachycardia crisis alarm. ©2021 Shu-Fen Wung All Rights Reserved

Low ECG QRS voltage, as seen in Figure 3, is denoted as nadir-to-peak QRS amplitudes of less than 5 mm in all the limb leads and less than 10 mm in all “precordial’ leads (Kim & Verdino, 2017).

Figure 3

An Example of a False Ventricular Tachycardia Crisis Alarm due to Low QRS Amplitude

The low QRS voltage of < 5 mm is seen in all limb leads (I, II, III) and the precordial V lead. ©2021 Shu-Fen Wung All Rights Reserved

The heart rate was calculated using the RR intervals. Of the 471 crisis alarm reviewed, only 11 heart rates (2.3%) truly matched with underlying rhythm and the heart rates inaccurately reflected the underlying rhythm in most alarms (n = 459, 95%).

DISCUSSION

Summary

This DNP project's findings showed a high level of inter-rater reliability with ECG crisis alarm interpretation. Of the annotated 471 crisis alarms from the arrhythmia alarm database, false crisis alarms commonly occurred in adult patients being monitored in the ICU. The frequency of false ECG crisis alarms was determined to be 95%. There are several major causes of false alarms. These include poor signal quality, artifacts, and low ECG amplitude.

The study also showed high inter-rater reliability in false alarm determination. There was almost a 100% agreement concerning whether the alarm was true or false. The agreement between two annotators' alarm interpretations was at an almost perfect level as supported by a kappa value of 0.98. Cohen's kappa, which considers hypothetical agreement and a value between 0.81-1.00 suggests almost perfect inter-rater agreement with limited faulty evidence (McHugh, 2012).

An ECG false alarm is a common occurrence in the ICU. The finding of this DNP project showed that 95% of crisis alarms in the ICU were false, which is higher than the study conducted by Drew et al. (2014) which showed a high number of false arrhythmia alarms (88.8%) in a hospital ICU setting. In a study conducted in the medical-surgical unit by Welch et al. (2016), continual vital sign assessment can improve patients' safety, however there is a concern for alarm fatigue resulting from multi-parameter continual vital signs monitoring. A study by Weller et al. (2018) showed that the average alarm rate in the non-ICU setting was 2.3 alarms per patient a day.

The potential causes of false crisis alarms identified were as follows; 0.45% of the false alarms were undetermined, artifacts caused 93.7% of the false alarms, and 59.2% of the false alarms were caused by low ECG amplitude. Artifacts can occur because of physiologic causes, such as body movement, coughing, respiration, shivering, tremors, or skin interferences. Non-physiologic causes can occur because of technical factors related to equipment problems, electrical interference from other surrounding electric devices, and power leakage (Sivaraks & Ratanamahatana, 2015).

Motion, muscle, and baseline wander artifacts can occur due to patient movement, which can cause a lead failure alarm in patients with intact electrodes and in patients where the integrity of the electrode is impaired. Sivaraks and Ratanamahatana (2015) proposed "an ECG anomaly detection algorithm as a strategy to differentiate ECG artifacts from real ECG signals." The use of a Robust and Accurate Anomaly Detection (RAAD) algorithm showed 100% sensitivity to uncover all anomaly beats. The algorithm utilizes the knowledge from a cardiologist to assess the ECG morphology and skills from time-series mining through the preprocessing step, cleanest lead discovering morphology segmentation, and robust anomaly detection. AC interference and baseline wander artifacts were suppressed through a reprocessing step that determines the proper cut-off frequency for band-pass filter RAAD to accurately detect anomaly beats even when the ECG is contaminated with artifacts (Sivaraks & Ratanamahatana, 2015). Future development of smart algorithms that have high sensitivity and specificity is needed to lower the false alarm burden.

Low ECG QRS voltage occurs due to conditions that impair the generation or the communication of electrical signals from the heart to the skin electrodes (Kim & Verdino, 2017). Low QRS voltage can occur due to pathological conditions and/or equipment and electrode failure (Hannibal, 2014). Hannibal (2014) proposed a systematic approach by troubleshooting mechanical and electrical problems alongside electrode placement customization based on the individual patient may produce fewer ECG false alarms related to low QRS voltage.

The heart rate analysis explored the relationship between heart rates and ECG alarms, as false heart rates can instigate a false ECG alarm and vice versa. A study by Dalwatte et al. (2018) proposed a novel ECG detector performance metric to determine the relationship with incorrect

heart rate limit alarm rates. The study concluded that an ECG beats detector has the potential to identify false alarm rates due to heart rate limit alarms and asystole alarms (Dalwatte et al.,2018).

Existing strategies are recommended to address and troubleshoot false ECG alarms. Allan et al. (2017) implemented alarm bundled reduction strategies in a cardiovascular surgical ICU setting that allowed nurses to reduce nonactionable alarms through adjusting default alarm thresholds for each alarm type on the physiologic monitors. These interventions improved the unit's alarms from the monitored beds without compromising patient safety (Allan et al., 2017). Nurse-led protocols, such as using a specific toolset, allowed nurses to make changes to patients' physiologic monitors. A survey conducted by Wyosocki (2021) concerning critical care nurses' experience with alarm types from physiological monitoring revealed that several strategies were utilized to troubleshoot alarms in the ICU setting. Such strategies included adjusting the physiologic monitor and parameter default settings, electrode replacement, and patient positioning (Wyosocki, 2021). The study by Weller et al. 2018 suggested that continual multi-parameter vital signs alarm settings could reduce high alarm rates. These above studies suggest that nurses' troubleshooting and customization interventions can help address false ECG alarms.

However, in the study by Drew et al. (2014), the findings suggest that nurses do not always customize alarm settings for their patients. Instead, these nurses utilize the hospital's monitor default alarm settings. Using a default alarm setting is inappropriate for patients in whom significant variations of other factors are present. Also, Sowan et al. (2016) discussed that changing default alarm settings and training on a cardiac monitor are insufficient in improving alarm safety. It is important for hospital leadership and manufacturers of the monitor to provide user-centered guidelines for nurses to adjust default settings based on their patients' monitoring

needs. An appropriate alarm management can improve patient care outcomes and nursing care experience in the ICU.

Interpretation

The ECG review was likely influenced by the annotator's knowledge base and interpretation of alarm events. To prevent interpretation biases, this project included two expert clinicians to evaluate inter-rater reliability with a third expert to evaluate the disagreements. Of the crisis alarms in the dataset, two were categorized as indeterminant due to lack of readable multi-channel ECGs signals, likely due to leads off. These two indeterminant alarms were not included in the Cohens kappa calculation for inter-rater reliability.

This project was limited as data were generated from a single unit; thus, the limiting the transferability and generalizability of project findings to another unit with a specific patient population. Therefore, the result of this project must be interpreted in the context of the ICU. A direct cause-and-effect relationship was not determined because there was no information on the patient's demographics available in this dataset. The dataset included limited information about the patient's age, gender, race, body mass index, and medical diagnosis, which would have otherwise allowed for further evaluation of other potential causes of a false or non-actionable crisis alarm.

Implications

Practice

Patient safety is a paramount concern in healthcare, and this DNP project highlighted the importance of differentiating false versus true crisis alarms. Although false alarms are commonly seen in cardiac monitoring, technical and human factors are crucial in effective ECG monitoring.

"Lack of training on alarm management by end-users, lack of alarm safety culture, and lack of multidisciplinary collaboration are all human-related factors that can account for the many ECG artifacts and low ECG amplitude causes of false ECG alarms" (Bach et al., 2018). The result of this study highlights specific challenges with technical and human factors causing ECG alarms to read as false. "Human, organizational, and technical factors should be considered to help develop an integrated approach in improving clinical alarm safety" (Bach et al., 2018). In the study by Sivaraks and Ratanamahatana (2015), technical-related cardiac monitor alarms such as electromagnetic interference and lead failure were examples of technical factor-related causes of false ECG alarms. In both human and technological factors related to causes of false ECG alarms, the use of standard ECG electrode placement was necessary for the proper rhythm interpretation (Block III & Block Jr., 2015). Physiological causes of ECG artifacts unrelated to cardiac electrical activity or the cardiac monitor could cause baseline and waves to be distorted. "Muscle, motion, and baseline wander artifacts are patient-related factors caused by rhythmic movement such as shaking, tremors, and a patient movement that can result in sudden irregularities in the ECG signals that may cause false arrhythmias" (Pérez-Riera et al., 2018).

False alarms caused by low voltage can occur with or without classic etiologies. This project showed 59.2% of low ECG voltage alarms as a potential cause for false alarms. According to Dzikowicz (2020), the three leading causes of low voltage, a QRS amplitude of 5mm or less in all the frontal leads and 10mm or less in the precordial leads, are due to extracardiac transmission, equipment-related issues, and cardiac voltage generation. Low amplitude QRS complexes can occur because of physiologic factors as seen in morbidly obese patients and patients with cardiac conditions like pericardial effusions and cardiac conduction

conditions like bundle branch block (Drew et al., 2014). As listed in the limitation section of the study, there was a lack of direct cause-and-effect relationship in which the dataset had limited information about the patients. Besides human-related factors, electrode placement, equipment, and an electrical malfunction could cause low voltage ECG alarms (Hannibal, 2014). A previously documented low voltage could guide clinicians to an expectation of expected voltage discordances.

Nurses, including registered nurses, advanced practice nurses, and nurse scientists, are the center of the multidisciplinary team responsible for monitoring patients and detecting arrhythmia. The ECG arrhythmia detection algorithm provided by Drew et al. (2014) effectively allowed the annotators to examine the multiple ECG leads for rhythm and alarm interpretation. Bedside clinicians, such as nurses, are frontline end-users of cardiac monitors. Measures to improve bedside nurses' knowledge of alarm management practices are critical to ensure safe use of the alarming devices, such as the cardiopulmonary monitors. In pursuit of promoting educational efforts for bedside nurses, hospital leadership should develop educational interventions through systematic and multidisciplinary clinical alarms response training. Effective clinical practice can be explored to improve education effectiveness in alarm management (Yue et al., 2016). Also, nurses are trained to use the nursing process to guide the care they provide to patients systematically. As part of the nursing process, assessment and evaluation allow the bedside nurse to decipher the issue surrounding ECG alarms and readily provide evaluations to decrease false alarms. For example, nurses can identify and prepare proper electrode sites to minimize muscle artifacts. Additionally, bedside nurses can be equipped with cardiac monitoring skills to troubleshoot cardiac monitoring issues to reduce false ECG

alarms and identify changes in patients' physiological states. Alarm training and education for end-users like bedside nurses should be ongoing to equip nurses with the skill set to handle alarm medical devices and provide safe individualized patient care.

The design of cardiac monitoring and the advancement in electrode technology plays a crucial role in cardiac monitoring techniques. In reviewing the ECGs during this study, two crisis alarms were indeterminants as there were no ECG signals available. Clinical ECG systems should be improved, including upgrading to innovative electrodes as well as lead-off detection methods. Manufacturers should improve the algorithms on physiologic monitors to enable accurate arrhythmia detection and false alarm suppression. Interprofessional collaboration with the leadership team and the engineers within the hospital that liaises with the manufacturers of the cardiac monitoring device to develop quality initiatives to address issues surrounding the cardiac monitoring device and its impact on patient safety.

DNP Essentials Addressed

This project focused on DNP Essentials I, II, III, VI, VII, and VIII, each of which addresses current practice issues, future practice issues, and the application of the research findings to improve healthcare and patient outcomes.

DNP Essential I: Scientific Underpinnings for Practice

DNP graduates are equipped with the scientific knowledge that can be translated into practice to help promote the progression of new practice approaches (AACN, 2006). This project integrated scientific knowledge with clinical practices to develop the best practices for managing false ECG alarms. The PDSA as a framework reviewed the evidence for the project, which provided insight concerning the issue of false ECG alarms and the need for a practice change.

DNP Essential II: Organizational and Systems Leadership for Quality Improvement and Systems Thinking

DNP graduates are equipped to hypothesize practical approaches that can address new practice problems at both organizational and system leadership levels to improve health outcomes (AACN, 2006). The project provided evidence-based findings to be disseminated at all levels of management to highlight the problem of false alarms and the need for practice change to promote patient safety.

DNP Essential III: Clinical Scholarship and Analytical Methods for Evidence-Based Practice

DNP graduates are scholars trained to recognize innovations and integration (AACN, 2006). This project demonstrated clinical scholarship to promote healthcare delivery changes by uncovering how false crisis alarms may affect patient safety and nursing practice. The project was able to connect theory to practice through a thorough synthesis of current literature and a review of false crisis alarms generated from the real-world clinical setting to improve quality and safety of patient monitoring.

DNP Essential VI: Interprofessional Collaboration for Improving Patient and Population Health Outcomes

DNP graduates are prepared to facilitate interprofessional collaboration through effective leadership to improve patient outcomes (AACN, 2006). This project has laid out plans for dissemination and sustainability of project findings and future directions for alarm management through interprofessional collaboration with a multidisciplinary team.

DNP Essential VII: Clinical Prevention and Population Health for Improving the Nation's Health

DNP graduates are positioned to be pacesetters in health promotion and disease prevention (AACN, 2006). This project provided insight concerning improving populations' health by investigating and analyzing evidence-based research, which uncovered a gap in the literature. This gap existed concerning the lack of proper ECG alarm management to propel future research in improving the nation's health goals concerning reducing false ECG alarms and promoting patient safety.

DNP Essential VIII: Advanced Nursing Practice

DNP graduates are trained in distinctive specialization within the larger domain of nursing (AACN, 2006). This project has provided information demonstrating how to transform current practice by equipping healthcare team members, such as advanced nurse practitioners, to make clinical judgments based on best practices that surround ECG alarm management.

Conclusions

Alarm safety is a complex problem and reducing false alarms in the acute care setting is a critical component in optimizing clinical alarm management practices in health care. Nurses are already faced with meeting the high demands of the healthcare industry and the overwhelming false monitoring alarms add to the care complexity and workload. Finding of this DNP project showed a high number of false crisis alarms in the ICU and provided insights to the potential causes of false crisis alarms. There is a critical need to develop quality alarm initiatives to decrease false ECG alarms. The causes of false crisis alarms can guide of the development of effective interventions that may reduce false ECG alarms, therefore improving patient safety and

outcomes. Despite this project's limitations, the findings provided resourceful information to guide practice changes and future research.

The PDSA theoretical framework guided this project. The author reviewed prior studies to help identify the frequency of false ECG alarms. The PDSA framework for this project proposed a practice change model in which the author created a systematic plan that can be used to inform and facilitate future research on false ECG alarms. Forming an interdisciplinary team is essential concerning promoting patient safety; the findings of this project can be shared with stakeholders of the ICU. This project provided a starting point for ICUs within the hospital to implement best practices when improving alarm management practices.

In conclusion, the objectives of this DNP project were met as it provided an analysis of the high number of false crisis alarms and the potential causes of such false alarms. This DNP project provided the information that can be used to understand and improve ECG alarm management. This study contributed to the existing literature by documenting false crisis alarms that occur in the ICU setting. The potential causes of false crisis alarms reported in this project can be used to develop efficient strategies to address the 2021 Hospital National Patient Safety Goals, the NPSG Goal Six (6) on Clinical Alarm Safety recommended by the Joint Commission (The Joint Commission, 2020b).

Plan for Dissemination and Sustainability

Patient safety is a vital concern at the national level, and practice alerts have been issued relating to alarm management and patient safety. The findings of this project are to be disseminated at all levels of management to highlight the problem of false alarms and the need for practice change to promote patient safety. This project provided workable strategies for

addressing the potential causes of false crisis alarms in the ICU, which could be disseminated to unit-based end users concerning the importance of reducing such false alarm alerts. The findings from this project can be shared with the nurse educators of the ICUs to design appropriate teaching strategies for nurses working with cardiac monitors.

To help promote sustainability, patient safety in the clinical care units require collaboration between hospital administration and bedside clinicians. Collaborative practice is essential as it ensures that the key stakeholders, both hospital administration and bedside clinicians, are fully engaged, which would propel the necessary changes to promote the best alarm management practices. A multidisciplinary task force team that includes bedside nurses, physicians, the director of clinical engineering, the unit nursing director, the nurse manager, the nurse educator, and the advanced nurse practitioner should explore the false alarm issues noted in this study. The multidisciplinary telemetry taskforce team can help identify ways to improve the utilization of cardiac monitoring and decide on team-based approaches that would reduce false ECG alarms in clinical settings.

Future Research

There is still a gap in decreasing false alarms in clinical practice and improving clinical alarm management, which may require moving along with the trajectory of technology advancement in healthcare. Since both technical and human-related factors account for the increasing causes of false ECG alarms, there is a growing need for further investigation on ECG anomaly detection. The literature cited prior evidence on the understanding that alarm customization default parameters based on patient clinical status can reduce alarm events (Bach et al., 2018). This project identified that a significant number of false alarms are caused by low

ECG amplitude and that increasing the signal gain on cardiac monitoring devices can solve low voltage issues. However, it is unknown if other factors besides gain adjustment can alleviate the problem of false alarms caused by low voltage. Other causes of false ECG alarms, such as artifacts resulting from motion, muscle, wandering baseline, intermittent signal, lead failure, and AC interference, can concurrently occur. According to Daluwatte et al. (2018), since the performance of ECG beat detectors can be assessed using sensitivity and positive predictive value to determine each heartbeat and detect any abnormalities, future studies are needed to investigate how heartbeat detector may help to reduce false ECG alarms.

The findings of this project also suggest that future research is needed to investigate a systematic approach to clinical alarm management by obtaining the best signal and reducing artifacts from sensors (Srinivasa et al., 2017). Data from this project can propel future research initiatives in clinical alarm management. Also, manufacturers of cardiac monitors and organizational leadership at hospitals should work closely to improve end users, such as bedside clinicians and engineering teams, usability on cardiac monitors, and promote alarm safety.

APPENDIX A:

THE UNIVERSITY OF ARIZONA INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

THE UNIVERSITY OF ARIZONA
Research, Discovery & Innovation

1618 E. Helen St.
P.O. Box 245137
Human Subjects
Tucson, AZ 85724-5137 Protection Program
Tel: (520) 626-6721 http://rgw.arizona.edu/compliance/home

Date: May 27, 2021
Principal Investigator: MILLICENT RAYDETTE OGOO

Protocol Number: 2105809227
Protocol Title: 'Profiling False ECG Alarms in the Medical-Surgical Unit'
Determination: Human Subjects Review not Required

Documents Reviewed Concurrently:

Data Collection Tools: *Alarm Annotation Protocol by Drew et al..docx*
HSPP Forms/Correspondence: *Advisor Confirmation Email.pdf*
HSPP Forms/Correspondence: *Ogoo IRB Determination of Human Research Final Revision 2021 05 22.pdf*
Informed Consent/PHI Forms: *OGOO IRB Disclosure Template Determination of HumanResearch.doc*
Other Approvals and Authorizations: *Permission to use de-identified dataset and be an annotator for her DNP project.pdf*

Regulatory Determinations/Comments:

- Not Human Subjects Research as defined by 45 CFR 46.102(e): as presented, the activities described above do not meet the definition of research involving human subjects as cited in the regulations issued by the U.S. Department of Health and Human Services which state that "Human subject means a living individual about whom an investigator (whether professional or student)conducting research: (i) Obtains information or biospecimens through intervention or interaction with the individual, and uses, studies, or analyzes the information or biospecimens; or (ii) Obtains, uses, studies, analyzes, or generates identifiable private information or identifiable biospecimens. "

The project listed above does not require oversight by the University of Arizona.
If the nature of the project changes, submit a new determination form to the Human Subjects Protection Program (HSPP) for reassessment. Changes include addition of research with children, specimen collection, participant observation, prospective collection of data when the study was previously retrospective in nature and broadening the scope or nature of the study activity. Please contact the HSPP to consult on whether the proposed changes need further review.

The University of Arizona maintains a Federalwide Assurance with the Office for Human Research Protections (FWA #00004218)

APPENDIX B:

CHART AUDIT FORMS (ALARM ANNOTATION PROTOCOL)

Alarm Label & Algorithm Definition	Proof of True versus False Alarm by Investigator
1. ASYSTOLE Displayed heart rate drops to zero. No QRS detected for ~5–6 seconds	**Proof of True Positive:** (either #1 or #2 confirms true alarm) 1. Simultaneous drop in invasive arterial or pulmonary artery (PA) pressure to near zero 2. Documentation from electronic medical record (EMR) of asystolic cardiac arrest at same time **Proof of False Positive:** (any of the following confirms false positive alarm) 1. No simultaneous decrease in invasive arterial or PA pressure 2. A visible QRS is evident in at least one ECG lead (examine all 7 available leads) 3. Good quality SpO2 signal has pulsatile waveform that matches rate of underlying baseline rhythm 4. ASYSTOLE alarm duration is >60 seconds but there is no EMR documentation that it was recognized clinically (syncope, seizure, loss of consciousness, cardiac arrest)
2. VFIB/VTAC Coarse flutter waves without QRS complexes	**Proof of True Positive:** (either #1 or #2 confirms true alarm) 1. Simultaneous drop in invasive arterial or PA pressure to near zero 2. Documentation from EMR of ventricular tachycardia or fibrillation cardiac arrest at same time **Proof of False Positive:** (any of the following confirms false positive alarm) 1. No simultaneous decrease in invasive arterial or PA pressure 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 SpO2 signal has pulsatile waveform that matches rate of underlying baseline rhythm 4. VFIB/VTAC alarm duration is >60 seconds but there is no EMR documentation that it was recognized clinically (syncope, seizure, loss of consciousness, cardiac arrest)
3. ACC VENT ≥6 ventricular beats with HR 50–100 bpm	**Proof of True Positive:** 1. Wide QRS beats are not preceded by a P wave with a consistent PR interval 2. Fusion beats are evident at the transition between ventricular rhythm and sinus rhythm **Proof of False Positive:** (either #1 or #2 confirms false positive alarm) 1. Event is sinus rhythm with BBB (P waves prior to each wide beat with consistent PR interval) 2. Patient is known to have ventricular pacemaker; event QRS matches paced rhythm on standard "diagnostic" 12-lead ECG
4. VTACH ≥6 consecutive PVCs with rate ≥100 bpm	**Proof of True Positive:** (any of the following confirms true positive alarm) 1. Simultaneous drop in invasive arterial or PA pressure 2. Documentation from EMR of VT at same time; standard 12-lead ECG documentation of VT read by cardiologist 3. Atrioventricular (AV) dissociation is evident throughout the wide QRS tachycardia in any ECG lead 4. Event wide QRS morphology is different than patient's baseline rhythm with 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 SpO2 signal has pulsatile waveform that matches rate of underlying baseline rhythm 4. VTACH alarm duration is >60 seconds but there is no EMR 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 leads matches a standard "diagnostic" 12-lead ECG acquired during ventricular pacing)
5. PAUSE 3-second interval without a QRS complex	**Proof of True Positive:** (either #1 or #2 confirms true alarm) 1. Simultaneous pause on invasive arterial or PA waveform 2. Simultaneous pause on good quality SpO2 waveform **Proof of False Positive:** (any of the following confirms false positive alarm) 1. No simultaneous pause in invasive arterial or PA pressure 2. No simultaneous pause on good quality SpO2 waveform 3. There is a visible QRS during the pause (may be low amplitude) in any of the 7 available leads
6. VBRADY ≥3 consecutive ventricular beats with HR ≤50 bpm	**Proof of True Positive:** 1. Rhythm is complete heart block with ventricular escape rhythm 2. Rhythm is sinus node arrest with ventricular escape rhythm **Proof of False Positive:** (either #1 or #2 confirms false positive alarm) 1. Event is sinus bradycardia with BBB (P waves prior to each beat with consistent PR interval) 2. Patient is known to have pacemaker; event QRS in all 7 leads matches paced rhythm on "diagnostic" 12-lead ECG

APPENDIX C:

LITERATURE REVIEW GRID

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
2020 Nguyen, S. C., Suba, S., Hu, X., & Pelter, M. M.	Double Trouble: Patients with Both True and False Arrhythmia Alarms.	Secondary Analysis: Prospective Observational Study	This study showed that physiologic bedside monitoring could detect both true and false alarms to trigger an alarm crisis for nurses to respond, raising concerns for the "cry wolf phenomenon" and its impact on patient safety from alarm fatigue.	This study enlightened the presence of true and false arrhythmias that can be seen by bedside cardiac monitoring and how these alarms can trigger a "cry-wolf phenomenon" or "raise a false alarm." However, true alarms can be missed, which becomes a problem for patients with true and false arrhythmia alarms.
2020 Fujita, L. Y., & Choi, S. Y.	Customizing Physiologic Alarms in the Emergency Department: A Regression Discontinuity, Quality Improvement Study.	Quality Improvement: A Retrospective Study	This project showed how changing default settings reduces false alarms. The study showed the need to customize cardiac monitors from a hospital-wide preset to a unit-specific one. This project helps create a protocol for staff to customize alarm settings based on clinical unit-specific and staff education to troubleshoot and adjust default settings.	This project showed that customizing default alarm settings based on unit-specific parameters can help reduce false alarms.
2020 Pelter, M. M., Suba, S., Sandoval, C., Zègre-Hemsey, J. K., Berger, S., Larsen, A., Badilini, F., & Hu, X.	Actionable Ventricular Tachycardia During In-Hospital ECG Monitoring and Its Impact on Alarm Fatigue	Secondary Analysis of Data: A Retrospective Research Design	The study provided insight into changing default alarm settings. The study findings suggest that adjusting cardiac monitors' default settings to > 130 beats/minute and duration of > 20 seconds might improve recognition of actionable V-tach. An algorithm-based approach was proposed for hospitals to adjust default alarm setting parameters as interventions to help reduce false alarm-related events.	This study provided insight into adjusting the default setting from the preset hospital, which is very sensitive to the setting that can improve arrhythmia recognition.
2019 Tscholl, D. W., Handschin, L., Rössler, J., Weiss, M.,	It's not you; it's the design - common problems with patient monitoring reported by anesthesiologists: a mixed qualitative and quantitative study.	A Mixed Method: (Integrating qualitative and	The study provided an overview of hardwires, human factors, and systemic factors impacting the cardiac monitors' overall design. The study suggested the need for an improved cardiac monitoring	This study provides the value of a well-designed cardiac monitor that can efficiently monitor patients on the cardiac monitors.

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
Spahn, D. R., & Nöthiger, C. B.		quantitative data)	device that can improve the problems in patient monitoring	
2019 Ruppel, H., Funk, M., Whittemore, R., Wung, S.F., Bonafide, C. P., & Powell Kennedy, H.,	Critical care nurses' clinical reasoning about physiologic monitor alarm customization: An interpretive descriptive study.	A Descriptive Qualitative Study: A qualitative Mixed Method Research Study	The study showed how alarm customization could affect false alarms. The study concluded that nurses would customize physiologic monitor alarms based on their technical and clinical expertise, the alarm culture on their clinical unit, colleagues' and patients' responses to notices that can ultimately improve unit alarm management.	This study provides information on how nurses can better understand physiological monitors' technical and clinical insight to help alarm customization specific to their unit.
2019 Poncette, A. S., Spies, C., Mosch, L., Schieler, M., Weber-Carstens, S., Krampe, H., & Balzer, F.	Clinical Requirements of Future Patient Monitoring in the Intensive Care Unit: Qualitative Study.	Exploratory Qualitative Research Study	This study focused on the value of nurses receiving training on alarm management. This study's findings showed a need to improve the nurse's knowledge of cardiac monitoring device usability. End-users like nurses should be part of the implementation process of digital healthcare technology transformation.	This study shows that it is essential to include the end-users regarding the device used in direct patient care when implementing novel technology in healthcare.
2019 Shue McGuffin, K., & Ortiz, S.	Daily Electrocardiogram Electrode Change and the Effect on Frequency of Nuisance Alarms	A Comparative Quantitative Research Design	This study provided insight into how daily electrode changes can decrease nuisance alarms in an inpatient telemetry unit.	This study reiterated that daily electrode changes reduced nuisance alarms to enhance patient safety and reduce alarms.
2017 Srinivasa, E., Mankoo, J., & Kerr, C.	An Evidence-Based Approach to Reducing Cardiac Telemetry Alarm Fatigue.	Quality Improvement: A Pilot Study	The study looked at an Evidence-based framework to identify the causes of alarm fatigue associated with cardiac telemetry monitoring and found that changes to alarm parameters can help reduce the noise level to optimize patient care and reduce alarm fatigue.	This DNP project was guided by the Plan Do Study Act conceptual framework to test a change at each stage of the project that investigates causes of alarm overload (the rate of alarms and noise level) on alarm fatigue.
2017 Petersen, E. M., & Costanzo, C. L.	Assessment of Clinical Alarms Influencing Nurses' Perceptions of Alarm Fatigue.	A Descriptive Qualitative Study: A	The nurse's perception response from the survey highlighted nine alarm issues that addressed adverse events, monitor watchers, alarm initiatives, and	This study provides recommendations for improved clinical alarm management by guiding policy creation on alarm

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
		Qualitative Survey Study	technological solutions. The most perceived problem of alarm fatigue reported in the survey was inadequate staffing. This study's findings showed the need for an improved alarm management system through assessment, policy creation, staff training, and ongoing quality improvement.	parameter adjustments, staff education, and sustainability.
2017 Yue, L., Plummer, V., & Cross, W.	The effectiveness of nurse education and training for clinical alarm response and management: a systematic review	A Systemic Review: Experimental Study Design	This study's findings showed that nurses' knowledge of clinical alarm management could be obtained by teaching and training nurses in the clinical practice or simulation to increase educational effectiveness on clinical alarm response and control.	The study showed the importance of training and education to create a "clinical alarm awareness' so that nurses can be knowledgeable about clinical alarm management.
2017 Funk, M., Fennie, K. P., Stephens, K. E., May, J. L., Winkler, C. G., Drew, B. J., & PULSE Site Investigators.	Association of Implementation of Practice Standards for Electrocardiographic Monitoring with Nurses' Knowledge, Quality of Care, and Patient Outcomes: Findings from the Practical Use of the Latest Standards of Electrocardiography (PULSE) Trial.	Randomized Clinical Trial	This study showed that improving nurses' education on ECG monitoring yielded effective patient arrhythmia monitoring and quality patient care.	This study showed the importance of nurses receiving educational training on ECG monitoring practice standards showed an improvement in knowledge on ECG monitoring and improved patient care.
2016 Pelter, M. M., Fidler, R., & Hu, X.	Research: Association of Low-Amplitude QRSs with False-Positive Asystole Alarms.	Secondary Analysis of Data. A Prospective Research Study	Twelve lead ECGs identified low amplitude QRSs measurements, which triggered a false-positive asystole alarm. This information serves as a baseline for nurses to select leads with tall QRSs with the patient's continuous cardiac monitoring to reduce false-positive asystole.	A 12 lead ECG serves as a baseline for patients at risk for low amplitude QRS and false alarms to help nurses select QRS leads during bedside cardiac monitoring to reduce the number of false alarms on such patients.
2016 Sadr, N., Huvanandana, J., Nguyen, D. T.,	Reducing false arrhythmia alarms in the ICU using multi-modal signals and robust QRS detection.	Secondary Analysis of Data: A retrospective	This study created an algorithm that utilized a multi-modal signal and robust QRS detector to detect five critical arrhythmias: Asystole, Extreme	This study is showed that a signal processing system could aid ECG arrhythmia recognition to help reduce false arrhythmia alarms.

Pub. Year; Author's Last Name	Title of Publication	Type of Study	Main Outcomes of Findings	Support for and or Link to Project
Kalra, C., McEwan, A., & de Chazal, P.		descriptive Research Design	Bradycardia, Extreme Ventricular, and Ventricular Fibrillation or Tachycardia.	
2015 Sendelbach, S., Wahl, S., Anthony, A., & Shotts, P. (2015).	Stop the Noise: A Quality Improvement Project to Decrease Electrocardiographic Nuisance Alarms.	Quality Improvement: Prospective Study Design	This study utilized a bundled approach intervention that included daily ECG electrode changes, disposable ECG leads, skin preparation, alarm customization, and duplicate alarms, which improved 80% to 90% reduction of false alarms with patients on cardiac monitors.	This study provided quality improvement initiatives like skin preparation and daily electrode changes as bundled interventions can be used with patients on the cardiac monitors.
2015 Walsh-Irwin, C. & Jurgens, C. Y.	Proper skin preparation and electrode placement decreases alarms on a telemetry unit.	Descriptive Quantitative Study: A Prospective Study	This study's findings showed that daily electrode changes and skin preparation reduce motion artifacts that are causes of false alarms.	This study was done in a telemetry unit. It provided insight into motion artifact as a cause of false alarm, which can be reduced if the patient receives proper skin preparation for electrode application and daily electrode changes.
2015 Crimlisk, J. T., Johnstone, D. J., & Winter, M. R.	Cardiac monitoring: Hospital-wide education and staff competence	Descriptive, Quantitative Study: A performance improvement study	This study showed the importance of a competency-based dysrhythmia test to improve staff competency on ECG monitoring for improved hospital processes and effective patient care delivery.	A dysrhythmia competency test for nurses on cardiac monitoring floors can help improve nurse competency on cardiac monitoring.

REFERENCES

American Association of Colleges of Nursing. (AACN). (2006, October). *The essentials of doctoral education for advanced nursing practice.* Washington, DC: https://www.aacnnursing.org/Portals/42/Publications/PhDPosition.pdf

Aboukhalil, A., Nielsen, L., Saeed, M., Mark, R. G., & Clifford, G. D. (2008). Reducing false alarm rates for critical arrhythmias using the arterial blood pressure waveform. *Journal of Biomedical Informatics, 41*(3):442-51. doi: 10.1016/j.jbi.2008.03.003

Allan, S. H., Doyle, P. A., Sapirstein, A., & Cvah, M. (2017). Data-driven implementation of alarm reduction interventions in a cardiovascular surgical ICU. *The Joint Commission Journal of Quality and Patient Safety, 43*(2), 62-70.

Association for the Advancement of Medical Instrumentation (2011). Clinical alarms: 2011 Summit.https://accenet.org/publications/Downloads/Reference%20Materials/2011%20Alarms%20Summit%20final%20low%20res.pdf

Bach, T. A., Berglund, L. M., & Turk, E. (2018). Managing alarm systems for quality and safety in the hospital setting. *BMJ Open Quality*, *7*(3), e000202. https://doi.org/10.1136/bmjoq2017-000202

Block, F. E. III & Block, F. E. Jr. (2015). Decreasing false alarms by obtaining the best signal and minimizing artifact from physiological sensors. *Biomedical Instrumentations & Technology, 49*(6):423-431. https://doi.org/10.2345/0899-8205-49.6.423

Brown, H., Terrence, J., Vasquez, P., Bates, D. W., & Zimlichman, E. (2014). Continuous monitoring in an inpatient medical-surgical unit: a controlled clinical trial. *The American Journal of Medicine, 127*(3), 226-232. doi: 10.1016/j.amjmed.2013.12.004

Casey, S. Avalos, G., & Dowling, M. (2018). Critical care nurse'' knowledge of alarm fatigue and practices towards alarms: a multicentre study. *Intensive Critical Care Nursing, 48*, 36-41. doi: 10.1016/j.iccn.2018.05.004.

Chuzi, S., Cantey, E. P., Unger, E., Rosenthal, J. E., Didwania, A., McGaghie, W. C., & Prenner, S. (2018). Interactive multi-modal curriculum on use and interpretation of inpatient telemetry. *MedEdPORTAL. The Journal of Teaching and Learning Resources,14*, 10730. doi: 10.15766/mep_2374-8265.10730. PMID: 30800930; PMCID: PMC6342405.

Clifford, C. D., Silva, I., Moody, B., Li, Q., Kella, D., Chahin, A., Kooistra, T., Perry, D. & Mark, R. G. (2016). Editorial: false alarm reduction in critical care. *Physiological Measurement, 37*(8), E5-E23. doi:10.1088/0967-3334/37/8/E5

Clifford, G. D., Silva, I., Moody, B., Li, Q., Kella, D., Shahin, A., Kooistra, T., Perry, D., & Mark, R. G. (2015). The physionet/computing in cardiology challenge 2015: reducing false arrhythmia alarms in the ICU. *Computer in Cardiology (2010),* 273-276. doi:10.1109/CIC.2015.7408639

Crimlisk, J. T., Johnstone, D. J., & Winter, M. R. (2015). Cardiac monitoring: hospital-wide education and staff competence. *Dimensions of Critical Care Nursing, 34*(3), 170-175. doi: 10.1097/DCC.0000000000000107

Daluwatte, C., Vicente, J., Galeotti, L., Johannesen, L., Strauss, D. G., & Scully, C. G. (2018). A novel ECG detector performance metric and its relationship with missing and false heart rate limit alarms. *Journal of Electrocardiology*, *51*(1), 68-73. https://doi.org/10.1016/j.jelectrocard.2017.08.030

Deming, W. E. (1988). *Out of the crisis*. Cambridge, MA: MIT Press.

Drew, B. J., Harris, P., Zègre-Hemsey, J. K., Mammone, T., Schindler, D., Salas-Boni, R., Bai, Y., Tinoco, A., Ding, Q., & Hu, X. (2014). Insights into the problem of alarm fatigue with physiologic monitor devices: a comprehensive observational study of consecutive intensive care unit patients. *PLoS ONE, 9*(10), e110274. doi:10.1371/journal.pone.0110274.

Dzikowicz, D. J. (2020). Low voltage on the 12 lead ECG: a warning sign. *Nurse Practitioner, 45*(9), 33-40. https://doi.org/10.1097/01.NPR.0000694724.36132.29

ECG & Echo Learning. (2008). *Clinical ECG interpretation*. https://ecgwaves.com/course/the-ecg-book/

Emergency Care Research Institute (2020). *Special report. Top 10 health technology hazards for 2020*. https://elautoclave.files.wordpress.com/2019/10/ecri-top-10-technology-hazards-2020.pdf

Food and Drug Administration. (FDA). (2019). *Medical device safety action plan: protecting patients, promoting public health*. https://www.fda.gov/about-fda/cdrh-reports/medical-device-safety-action-plan-protecting-patients-promoting-public-health

Food and Drug Administration. (FDA). (2011). *FDA patient safety news: show #106*. http://www.fda.gov/downloads/Safety/FDAPatientSafetyNews/UCM417915.pdf2016

Francis, J. (2016). ECG monitoring leads and special leads. *Indian Pacing Electrophysiology Journal, 16*(3), 92-95. doi:10.1016/j.ipej.2016.07.003

Fries-Gaither, J. (2010). *Summarizing and synthesis: what's the difference?* https://beyondpenguins.ehe.osu.edu/issue/climate-change-and-the-polar-regions/summarizing-and-synthesizing-whats-the-difference

Fujita, L. Y. & Choi, S. Y. (2020). Customizing physiologic alarms in the emergency department: a regression discontinuity, quality improvement study. *Journal of Emergency Nursing, 46*(2), 188-198.e2. doi:10.1016/j.jen.2019.10.017

Funk, M., Fennie, K. P., Stephens, K. E., May, J. L., Winkler, C. G., Drew, B. J., & PULSE Site Investigators, (2017). Association of implementation of practice standards for electrocardiographic monitoring with nurses' knowledge, quality of care, and patient outcomes: findings from the practical use of the latest standards of electrocardiography (PULSE) trial. *Circulation, Cardiovascular Quality and Outcomes, 10*(2), e003132. doi:10.1161/CIRCOUTCOMES.116.003132

Hannibal, G. B. (2014). Interpretation of the low-voltage ECG. *Advanced Critical Care, 25*(1), 64-68.

Healthcare Technology Foundation (2016). *HTF update: 2016 national clinical alarm survey results*. http://www.thehtf.org/documents/2016%20National%20Clinical%20Alarms%20Survey%20Results.pdf

Jacques, S. (2016). Breaking barriers to patient-centric alarm management. *Biomedical Instrumentation & Technology, 50*(3), 181-183. doi:10.2345/0899-8205-50.3.181

Karnik, A. & Bonafide, C. P. (2015). A framework for reducing alarm fatigue on pediatric inpatient units. *Hospital Pediatrics, 5*(3):160-3. doi: 10.1542/hpeds.2014-0123

Kim, D. H. & Verdino, R. J., (2017). Electrocardiogram voltage discordance: interpretation of low QRS voltage only in the precordial leads. *Journal of Electrocardiology*, *50*(5), 551-554. https://doi.org/10.1016/j.jelectrocard.2017.04.016

Krasteva, V., Jekova, I., Leber, R., Schmid, R., & Abächerli, R. (2016). Real-time arrhythmia detection with supplementary ECG quality and pulse wave monitoring for the reduction of false alarms in ICUs. *Physiological Measurement, 37*(8). 1273-1297. doi:10.1088/0967-3334/37/8/1273

Laerd Statistics (2019). *Fleiss' kappa using SPSS statistics. statistical tutorials and software guides*. https://statistics.laerd.com/spss-tutorials/fleiss-kappa-in-spss-statistics.php

Langley, G. J., Moen, R. D., Nolan, K. M., Nolan, T. W., Normal, C. L., & Provost, L. P. (2009). *The improvement guide: a practical approach to enhancing organizational performance* (2nd ed.). San Francisco, CA: Jossey-Bass.

Leis, J. & Shojania, K. (2016). A primer on PDSA: executing plan–do–study–act cycles in practice, not just in name. *BMJ Quality & Safety, 26*(7), 572-577. https://doi.org/10.1136/bmjqs-2016-006245

Managing alarms in acute care across the life span: electrocardiography and pulse oximetry. (2018). *Critical Care Nurse*, *38*(2), e16-e20. https://doi.org/10.4037/ccn2018468

McHugh, M. L. (2012). Interrater reliability: the kappa statistic. *Biochemia Medica, 22*(3). 276-282.

McQuillan, R. F., Silver, S. A., Harel, Z., Weizman, A., Thomas, A., Bell, C., Chertow, G. M., Chan, C. T., & Nesrallah, G. (2016). How to measure and interpret quality improvement data. *Clinical Journal of the American Society of Nephrology, 11*(5), 908-914. doi:10.2215/CJN.11511015

Moss, M., Good, V. S., Gozal, D., Kleinpell, R., & Sessler, C. N., (2016). An official critical care societies collaborative statement-burnout syndrome in critical care health-care professionals: a call for action. *Chest, 150*(1), 17-26. doi:10.1016/j.chest.2016.02.649

Nguyen, S. C., Suba, S., Hu, X., & Pelter, M. M. (2020). Double trouble: patients with both true and false arrhythmia alarms. *Critical Care Nursing, 40*(2), 14-23. doi:10.4037/ccn2020363.

Pelter, M. M., Suba, S., Sandoval, C., Zègre-Hemsey, J. K., Berger, S., Larsen, A., Badilini, F., & Hu, X. (2020). Actionable ventricular tachycardia during in-hospital ECG monitoring and its impact on alarm fatigue. *Critical Pathways in Cardiology, 19*(2), 79-86. doi:10.1097/HPC.0000000000000216

Pelter, M. M., Fidler, R., & Hu, X. (2016). Research: association of low-amplitude QRSs with false-positive asystole alarms. *Biomedical Instrumentation Technology,50*(5), 329-335. doi:10.2345/0899-8205-50.5.329

Pérez-Riera, A. R., Barbosa-Barros, R., Daminello-Raimundo, R., & de Abreu, L. C. (2018). Main artifacts in electrocardiography. *Annals of Noninvasive Electrocardiology: The Official Journal of the International Society for Holter and Noninvasive Electrocardiology, Inc*, *23*(2), e12494. https://doi.org/10.1111/anec.12494

Petersen, E. M. & Costanzo, C. L. (2017). Assessment of clinical alarms influencing nurses' perceptions of alarm fatigue. *Dimensions of Critical Care Nursing,36*(1), 36-44. doi:10.1097/DCC.0000000000000220

PhysioNet (2015). *Reducing false arrhythmia alarms in the ICU - the physionet computing in cardiology challenge 2015*. https://physionet.org/content/challenge-2015/1.0.0/

Poncette, A. S., Spies, C., Mosch, L., Schieler, M., Weber-Carstens, S., Krampe, H., & Balzer, F. (2019). Clinical requirements of future patient monitoring in the intensive care unit: qualitative study. *JMIR Medical Informatics, 7*(2), e13064. doi:10.2196/13064

Provost, L. P. & Murray, S. K. (2011). *The health care data guide. Learning from data for Improvement* (2nd ed.). San Francisco, CA: John Wiley & Sons, Inc.

Raj, S., Ray, K. C., & Shankar, O. (2018). Development of robust, fast, and efficient QRS complex detector: a methodological review. *Australasian Physical & Engineering Sciences in Medicine, 41*(3), 581-600. doi:10.1007/s13246-018-0670-7

Ruppel, H., Funk, M., Whittemore, R., Wung, S. F., Bonafide, C. P., & Powell Kennedy, H., (2019). Critical care nurses' clinical reasoning about physiologic monitor alarm customization: an interpretive descriptive study. *Journal of Clinical Nursing, 28*(15-16), 3033-3041. doi:10.1111/jocn.14866

Ruppel, H. & Funk, M. (2018). Nurse-technology interactions and patient safety. *Critical Care Nursing Clinics of North America, 30*(2), 203-213. doi:10.1016/j.cnc.2018.02.003

Ruppel, H., Funk, M., Kennedy, H. P., Bonafide, C. P., Wung, S. F., & Whittemore, R. (2018). Challenges of customizing electrocardiography alarms in intensive care units: a mixed methods study. *Heart Lung, 47*(5), 502-508. doi:10.1016/j.hrtlng.2018.06.010

Sadr, N., Huvanandana, J., Nguyen, D. T., Kalra, C., McEwan, A., & de Chazal, P. (2016). Reducing false arrhythmia alarms in the ICU using multi-modal signals and robust QRS detection. *Physiological Measurement, 37*(8), 1340-1354. doi:10.1088/0967-3334/37/8/1340.

Sandau, K. E., Funk, M., Auerbach, A., Barnsness, G. W., Blum, K., Cvach, K., Lampert, R., May, J. L., McDaniel, G. M., Perez, M. V., Sendelbach, S., Sommargren, C. E., & Wang, P. J. (2017). Update to practice standards for electrocardiographic monitoring in hospital settings: a scientific statement from the American Heart Association. *Circulation, 136*(19), e273-e344. https://doi.org/10.1161/CIR.0000000000000527

Sendelbach, S., Wahl, S., Anthony, A., & Shotts, P. (2015). Stop the noise: a quality improvement project to decrease electrocardiographic nuisance alarms. *Critical Care Nurse, 35*(4), 15-22; quiz 1p following 22. doi:10.4037/ccn2015858

Shue McGuffin, K. & Ortiz, S. (2019). Daily electrocardiogram electrode change and the effect on frequency of nuisance alarms. *Dimensions of Critical Care Nursing, 38*(4), 187-191. doi: 10.1097/DCC.0000000000000362

Sivaraks, H. & Ratanamahatana, C. A. (2015). Robust and accurate anomaly detection in ECG artifacts using time series motif discovery. *Computational and Mathematical Methods in Medicine*, *2015*, 453214-453220. https://doi.org/10.1155/2015/453214

Sowan, A. K., Gomez, T. M., Tarriela, A. F., Reed, C. C., & Paper, B. M. (2016). Changes in default alarm settings and standard in-service are insufficient to improve alarm fatigue in an intensive care unit: a pilot project. *JMIR Human Factors*, *3*(1), e1. https://doi.org/10.2196/humanfactors.5098

Srinivasa, E., Mankoo, J., & Kerr, C. (2017). An evidence-based approach to reducing cardiac telemetry alarm fatigue. *Worldviews on Evidence - Based Nursing,14*(4), 265-273. doi:10.1111/wvn.12200

Stoltzfus, K. B., Bhakta, M., Shankweiler, C., Mount, R. R., & Gibson, C. (2019). Appropriate utilization of cardiac telemetry monitoring: a quality improvement project. *BMJ Open Quality, 8*(2), e000560. doi: 10.1136/bmjoq-2018-000560

The Emergency Care Research Institute. (2020). *Special report. Top 10 health technology hazards for 2020*. https://elautoclave.files.wordpress.com/2019/10/ecri-top-10-technology-hazards-2020.pdf

The Joint Commission. (2020a). *2020 national patient safety goals*. https://www.jointcommission.org/standards/national-patient-safety-goals/-/media/c27cb0eca3154375a6da1ec2a7ed4c6f.ashx

The Joint Commission. (2020b). *2021 hospital national patient safety goals*. https://www.jointcommission.org/-/media/tjc/documents/standards/national-patient-safety-goals/2021/simplified-2021-hap-npsg-goals-final-11420.pdf

The Joint Commission. (2013). *Medical device alarm safety in hospitals*. https://www.jointcommission.org/-/media/tjc/documents/resources/patient-safety-topics/sentinel-event/sea_50_alarms_4_26_16.pdf

Tscholl, D. W., Handschin, L., Rössler, J., Weiss, M., Spahn, D. R., & Nöthiger, C. B. (2019). It's not you, it's the design - common problems with patient monitoring reported by anesthesiologists: a mixed qualitative and quantitative study. *BMC Anesthesiology, 19*(1), 87. doi:10.1186/s12871-019-0757-z

Turmell, J. W., Coke, L., Catinella, R., Hosford, T., & Majeski, A. (2017). Alarm fatigue: use of an evidence-based alarm management strategy. *Journal of Nursing Care Quality, 32*(1), 47-54. doi:10.1097/NCQ.0000000000000223

Walsh-Irwin, C. & Jurgens, C. Y. (2015). Proper skin preparation and electrode placement decreases alarms on a telemetry unit. *Dimensions of Critical Care Nursing, 34*(3), 134-139. doi:10.1097/DCC.0000000000000108

Whalen, D. A., Covelle, P. M., Piepenbrink, J. C., Villanova, K. L., Cuneo, C. L. & Awtry, E. H. (2014). Novel approach to cardiac alarm management on telemetry units. *The Journal of Cardiovascular Nursing, 29*(5), E 13-22. doi: 10.1097/JCN.0000000000000114

Welch, J., Kanter, B., Skora, B., McCombie, S., Henry, I., McCombie, D., Kennedy, R., & Soller, B. (2016). Multi-parameter vital sign database to assist in alarm optimization for general care units. *Journal of Clinical Monitoring and Computing, 30*(6), 895-900.

Weller, R. S., Foard, K. L., & Harwood, T. N. (2018). Evaluation of a wireless, portable, wearable multi-parameter vital signs monitor in hospitalized neurological and neurosurgical patients. *Journal of Clinical Monitoring and Computing, 32*(5), 945-951.

Wysocki, C. J. (2021). Critical care nurses' thinking process to trouble shoot physiologic monitor alarms. [Doctoral dissertation, University of Arizona, Tucson, USA]

Yue, L., Plummer, V., & Cross, W. (2017). The effectiveness of nurse education and training for clinical alarm response and management: a systematic review. *Journal of Clinical Nursing, 26*(17-18), 2511-2526. doi:10.1111/jocn.13605

Zong, W., Nielsen, L., Gross, B., Brea, J., & Frassica, J. (2016). A practical algorithm to reduce also critical ECG alarms using arterial blood pressure and/or photoplethysmogram waveforms. *Physiological Measurement, 37*(8), 1355-1369. doi: 10.1088/0967-3334/37/8/1355