# RESEARCH Video Methods for Evaluating Physiologic Monitor Alarms And Alarm Responses

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## Abstract

False physiologic monitor alarms are extremely common in the hospital environment. High false alarm rates have the potential to lead to alarm fatigue, leading nurses to delay their responses to alarms, ignore alarms, or disable them entirely. Recent evidence from the U.S. Food and Drug Administration (FDA) and The Joint Commission has demonstrated a link between alarm fatigue and patient deaths. Yet, very little scientific effort has focused on the rigorous quantitative measurement of alarms and responses in the hospital setting.

We developed a system using multiple temporarily mounted, minimally obtrusive video cameras in hospitalized patients' rooms to characterize physiologic monitor alarms and nurse responses as a proxy for alarm fatigue. This allowed us to efficiently categorize each alarm's cause, technical validity, actionable characteristics, and determine the nurse's response time.

We describe and illustrate the methods we used to acquire the video, synchronize and process the video, manage the large digital files, integrate the video with data from the physiologic monitor alarm network, archive the video to secure servers, and perform expert review and annotation using alarm "bookmarks." We discuss the technical and logistical challenges we encountered, including the root causes of hardware failures as well as issues with consent, confidentiality, protection of the video from litigation, and Hawthorne-like effects.

The description of this video method may be useful to multidisciplinary teams interested in evaluating physiologic monitor alarms and alarm responses to better characterize alarm fatigue and other patient safety issues in clinical settings.

## Introduction

Physiologic monitors are medical devices intended to prevent cardiac and respiratory arrest in ill patients by alerting clinicians to signs of evolving instability. Modern monitors can simultaneously display heart rate, electrocardiographic waveform, respiratory rate, blood pressure, oxygen saturation, and other parameters.<sup>1</sup> Bedside nurses serve on the front line, taking responsibility for integrating the vast amount of data continuously being displayed on the physiologic monitors of multiple patients, identifying signs of deterioration, and determining the appropriate initial action. To permit nurses to direct their attention to other patient care responsibilities simultaneously, physiologic monitors are equipped with alarms. To minimize the probability that monitors will miss early signs of deterioration, manufacturers design alarm algorithms that prioritize sensitivity at the expense of specificity.<sup>2</sup> As a result, the devices generate very frequent alarms (averaging between 39 and 352

alarms per patient, per day).<sup>310</sup> A high proportion of these alarms are false (68-86% of pediatric<sup>3,4</sup> and 46-85% of adult<sup>5-10</sup> intensive care unit [ICU] alarms). In a variety of settings, it has been shown that people rapidly learn to ignore alarms<sup>11,12</sup> or respond to alarms more slowly when exposed to high false alarm rates.<sup>13</sup> This phenomenon is known as alarm fatigue.<sup>14</sup>

National surveys of healthcare providers suggest that alarm fatigue is an important hospital safety issue, with respondents reporting that high alarm rates interrupt patient care, reduce trust in alarms, and lead clinicians to disable alarms entirely.15,16 The FDA recently identified 566 reports of alarm-related deaths between 2005 and 2008, calling attention to the potential harm associated with alarms.<sup>17,18</sup> On April 8, 2013, The Joint Commission issued a Sentinel Event Alert on alarm fatigue, citing 80 deaths attributable to alarm fatigue and other alarm problems between 2009 and 2012.19 A proposed 2014 Joint Commission National Patient Safety Goal focusing on alarm management has been released and will likely result in major efforts to evaluate and improve alarm management.20

While the link between high alarm rates and alarm fatigue has been widely proposed, the degree to which nurse response time is actually affected in the course of routine care has not been evaluated.

Video recording has emerged as an innovative method to drive improvements in quality and safety;<sup>21–23</sup> it is especially well-suited for evaluating monitor alarms and alarm fatigue.<sup>10,24</sup> In contrast to traditional observational methods, the use of video allows simultaneous visualization of the monitor's waveforms and alarms, the patient's activity level and condition, and the precise timing and nature of the nurse's response. Multiple reviewers can evaluate the video recordings asynchronously and make independent determinations about the content.

Therefore, we set out to develop a novel, video-based approach to study physiologic monitor alarms and quantify alarm fatigue. Very little was available in the scientific literature or the consumer press to guide equipment selection or research methodology, so we had to define these ourselves through experimentation and consultation with experts. In this article, we describe the system that resulted from these efforts with the expectation that others will find this method useful in quantitatively evaluating alarm fatigue and other patient safety issues.

# Methods

# Setting

We developed this framework for studying alarms at The Children's Hospital of Philadelphia (CHOP). CHOP is an urban, tertiary care children's hospital with 535 beds. A physiologic monitor is wall-mounted beside every inpatient bed. All patients in the ICUs receive continuous physiologic monitoring using General Electric (GE) Solar 8000i or 8000m bedside monitors. The monitors are capable of simultaneously displaying data from the following channels: electrocardiogram, temperature, respiration, non-invasive blood pressure, invasive blood pressure, other invasive pressures (i.e., central venous, intracranial, bladder), pulse oximetry, carbon dioxide, and cardiac output. Some ventilators can be directly connected to the monitoring network through a GE Unity Network Interface Device, allowing ventilator data and alarms to be displayed simultaneously on both the ventilator and bedside monitor. Patients hospitalized in non-ICU settings are monitored using GE Dash 3000, 4000, or 5000 bedside monitors if ordered.

# Visual Alerts and Audible Alarms

The GE Solar 8000 monitors include four clinical alarm levels (patient crisis, patient warning, patient advisory, and patient message) and two technical alarm levels (system warning and system advisory). The GE Dash monitors have the same configuration, plus a system message alarm level. All alarm levels display visual on-screen alerts. All levels except patient message and system message also feature an audible alarm. All levels except patient message, system message, and system advisory also fire at central stations available on some units for the convenience of bedside nurses. These are infrequently used, and none of the units we studied had staff serving as dedicated monitor watchers. We have included a table of alarm defaults at each level (Table 1).



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Alarm settings				
	PICU	Ward		
ASYSTOLE	Crisis Crisis			
BRADY	Crisis	Crisis		
V BRADY	Crisis	Advisory		
V TACH	Crisis	Crisis		
VFIB/VTACH	Crisis	Crisis		
HR (ECG leads)	Warning	Warning		
RR (ECG leads)	Warning	Warning		
RESP APNEA	Warning	Warning		
SpO2	Warning	Warning		
TACHY	Advisory	Crisis		
TRIGEMINY	Advisory	Warning		
BIGEMINY	Advisory	Advisory		
PVC	Advisory	Advisory		
R ON T	Advisory	Advisory		
ST	Advisory	Advisory		
PAUSE	Advisory	Advisory		
COUPLET	Advisory	Advisory		
IRREGULAR	Advisory	Advisory		
VT >2	Advisory	Advisory		
NBP	Advisory	Advisory		
ABP	Advisory	N/A		
VENT ALARM	Advisory	N/A		
CVP	Advisory	N/A		
EXP CO2	Advisory	N/A		
RR (CO2 sensor)	Advisory N/A			
HR (SpO2 sensor)	Message	Message		

**Table 1.** Patient Alarm Default Settings for TheChildren's Hospital of Philadelphia

	Infant <6mo	Infant 6mo-1yr	Child	Adult	
HR high	180	180	120	100	
HR low	100	80	60	55	
RR high	70	60	30	30	
RR low	20	20	15	12	
Apnea time (secs)	15	15	20	20	
Pulse oximetry high	101	101	101	101	
Pulse oximetry low	90	90	90	90	
Abbreviations: HR, heart rate; mo, months; RR, respiratory rate; secs, seconds; yr, year.					

Table 2. Profile Choices for Initial Monitor Parameters

## **Monitor Parameters**

On admission, initial monitor parameter settings are ordered by a physician using an order set in the electronic health record. They are presented with four profile options that vary based on age group (Table 2). Based on the characteristics of the patient, any of these parameters can be modified by the physician in the order at the time of admission, or at any point during the hospital stay. In addition, hospital policy states that a patient's assigned nurse may make a change in an alarm parameter that is outside the range indicated in the patient care order and update the patient care order accordingly, and must document communication with the attending physician or his/her designee regarding this action in the medical record.

## Scope

Our broad objective was to develop a method to evaluate physiologic monitor alarms and their responses in order to begin objectively studying alarm fatigue. Specifically, for each alarm captured on video, we aimed to collect the data elements in Table 3. In developing this video method, we recorded 40 six-hour sessions between Aug. 1, 2012, and July 31, 2013, with 20 sessions occurring in a 55-bed pediatric ICU and 20 sessions occurring on a 20-bed general inpatient ward. During the sessions, we did not restrict any aspect of patient care, and the nurse was not prevented from changing the alarm parameters during his or her shift.

## Alarm Categorization Scheme

We used the data elements from Table 3 to categorize each alarm's cause, technical validity, and actionable characteristics. We adapted these categories from a taxonomy for monitor alarm annotations originally developed by Siebig and colleagues.<sup>10,24</sup> We included all alarms, regardless of duration. We considered alarms to be true, or clinically relevant, if they met all of the following conditions: they were not induced, they were technically valid, and they were either actionable or alerting (Figure 1). We considered the others to be false, or not clinically relevant.



**Figure 1.** Determination of Clinically Relevant Alarms. Alarms are classified within each of the categories shown above (alarm cause, technical validity, and actionable determination). Alarms that fall into any of the boxes shaded grey are considered false, or not clinically relevant. Only alarms that fall into unshaded boxes for all three categories are considered true, or clinically relevant.

### Camera Placement

To enable our team to accurately and reliably determine each alarm's cause, technical validity, actionable characteristics, and nurse response time, we needed to, at a minimum, be able to simultaneously see: (1) a wide view of the patient room, (2) a close view of the patient (with an overhead view ideal), full views of (3) the monitor screen and (4) ventilator display (if in use), and (5) a view of any windows or doors through which staff could visually assess the patient or monitor without entering the room. In order to support this setup, our team developed the set of technical requirements in Table 4. Depending on the number of cameras needed to adequately cover the room, monitor, and ventilator (if applicable), we were able to record at up to three bedsides simultaneously using a total of 11 cameras.

## **Camera Selection**

We identified the GoPro Hero 3 as a camera that met all of the requirements for our project. These cameras were designed primarily to shoot action sports such as surfing, skydiving, and auto racing, and are thus designed to be rugged, portable, easy to use, and reliable. During initial testing we found that they were capable of shooting high definition video, had a very wide field of

#### **Alarm details**

Alarm type (i.e. heart rate, arrhythmia, oxygen saturation). Alarm duration.

For parameter alarms, the most extreme value occurring during the alarm (i.e. 120 for a high heart rate alarm that fired when the threshold of 100 was reached but went up to 120 during the alarm condition).

#### Alarm causes

Was the alarm due to the patient moving around on his/her own? Was the alarm due to someone manipulating/moving the patient or equipment?

#### Alarm technical validity

Does the alarm appear to correctly identify the physiologic status of the patient?

#### Alarm response time

Was the RN, physician, respiratory therapist, or nurse practitioner in the room when the alarm went off?

If not:

Elapsed time from alarm triggering to RN visualizing patient/monitor from outside room, if applicable.

Elapsed time from alarm triggering to RN entering room, if applicable. Elapsed time from alarm triggering to RN evaluating patient/equipment at the bedside, if applicable.

#### Actionable determination

Did the alarm indicate a condition or trend that led (or should have led) to a clinical intervention, such as suctioning the patient or increasing the oxygen level?

Did the alarm indicate a condition or trend that led (or should have led) to consultation with another clinician (such as a charge nurse, respiratory therapist, or physician) at the bedside to evaluate the patient/ equipment?

#### **Parameter changes**

Did staff change alarm parameters in response to this alarm?

Table 3. Data Elements Collected for Each Alarm

Category	Specification	Justification
Video quality	High definition	To permit digitally zooming within frame during post processing if necessary to view patient or staff
Field of view	Wide	To allow for capture of as much of hospital room as possible, even with suboptimal positioning
Low light performance	Ability to capture video in low light settings	To allow recording in dimly lit hospital rooms without requesting that staff/families turn on lights
Number of cameras	Ability to film using multiple cameras in one patient room	To permit recording in rooms with complex layouts and a wide range of monitoring equipment in use
Camera independence	Ability to use multiple cameras without requiring them to be physically or wirelessly connected	To reduce complexity of set up
Sound quality	High	To facilitate review of alarms when discussions amongst staff occur related to cause of alarm and actions required
Storage capacity	Ability to store 6 hours of high-definition video	To allow uninterrupted recording without need to replace memory cards or devices in the midst of a recording session
Power capacity	Ability to record for 6 hours using extended-life battery or ability to record while plugged in	To allow uninterrupted recording without need to replace batteries or devices in the midst of a recording session
Viewfinders	Physical and remote viewfinder options	To facilitate setup of video ensuring area of interest is captured in field of view, including when a physical viewfinder on the back of a camera is not easily accessed (i.e., when camera mounted on top of crib)
Infection control	Ability to be cleaned after use in patient care environment using methods consistent with hospital policy	To minimize likelihood of spreading infection
Form factor	Very compact	To minimize obtrusiveness to patient, family, staff
External lights and indicators	Ability to disable or mask external flashing lights or other indicators	To minimize reminders that the room is being video recorded (reduce Hawthorne effect) and minimize disruptions to patient, family, staff
Mounting	Wide range of temporary mounting options without taking up any floor space, obstructing critical equipment, or limiting access to the patient's bedside	The patient care environment already contains a wide range of equipment that occupies floor space (pumps, ventilators, medication carts, computers on wheels, etc.), and we did not want to further clutter the environment or hinder access to the patient or equipment
Reliability	Ability to be used repeatedly without power failures or data corruption	To minimize the number of nonevaluable video sessions
Ruggedness	Ability to withstand repeated transport, setup, and takedown	To minimize damage to cameras during repeated use
Portability	Ability for one person to easily transport all equipment to any room in the hospital	To minimize staff required to support study
Ease of setup	Ability for two people to completely set up system in under 20 minutes in any hospital room	To minimize staff required to support study, maximize ratio of recording time to setup time, and minimize disruptions to patient, family, staff
Synchronization	Ability for multiple cameras to be synchronized	To facilitate video review of alarms
Cost	Affordable on a limited study budget	To permit those with limited funding to begin studying excessive alarms and their consequences
Post-processing, editing time	Minimal time required to process independent raw video files from cameras into a single video file	To facilitate video review of alarms

Table 4. Technical Requirements



Figure 2. Examples of Camera Mounting Options in a Patient's Hospital Room. Clockwise from upper left: GoPro suction cup mount attached to window, use of wireless viewfinder with camera facing down mounted on top of patient's clear-top crib, Articulating Magic Arm with Super Clamp attached to GE Dash 3000 monitor handle, Kupo Max Arm attached to television wall mount.

view, performed well in low light, captured high-quality audio, had high data storage capacity (up to 64 gb on a memory card), were capable of filming while plugged in to eliminate the need for multiple batteries, had optional liquid-crystal display (LCD) viewfinders as well as an app that allows Apple iOS or Android devices to serve as remote wireless viewfinders, could be cleaned using hospital-approved disinfectant wipes, had a compact form factor, had external blinking lights that can be disabled, and had extensive mounting options using standard tripod mounts. Depending on the model, they cost \$200-\$400 each.<sup>25</sup>

# Video System and Workflow

*Camera Configuration, Mounting, and Storage* We outfitted each camera with a removable LCD viewfinder (GoPro LCD BacPac, \$80), a GoPro Frame (\$40), and a GoPro Tripod Adapter (\$8). After testing a wide range of mounting options, we selected four devices that allowed us to temporarily attach cameras to a variety of surfaces in a patient's room without taking up floor space, obstructing critical equipment, or limiting access to the patient's bedside. They included the following models:

- GoPro suction cup mount (\$30)
- Dinkum Systems Clamping ActionPod mount (\$35)
- Articulating 11-inch Magic Arm with Super Clamp (\$40)
- Kupo Max Arm with Kupo Convi Clamp and Kupo Camera/Umbrella Bracket (\$150)

Using that equipment, we mounted cameras to windows, shelves, monitor mounts, television mounts, cribs, and other surfaces in the patient room (Figure 2).

Cameras were powered by wall outlets using Mini-B 5-pin to USB 2.0 cables (\$10) connected to the GoPro wall charger (\$40). After testing a wide range of mounting options, we selected four devices that allowed us to temporarily attach cameras to a variety of surfaces in a patient's room without taking up floor space, obstructing critical equipment, or limiting access to the patient's bedside. To prevent staff from tripping on cables or accidentally dislodging them from the cameras, we secured them using two-inch wide gaffer's tape (\$22).

We stored all of our cameras and mounts in a wheeled, lockable medical cart (Harloff five drawer mini line anesthesia cart, \$1,000). This allowed us to easily transport our equipment to the study unit each day, and keep backup cameras and equipment readily available but stored securely on the unit.

## Camera Synchronization

Prior to mounting the cameras in the room, we synchronized them using an electronic clapperboard app (Movie Slate, www.movieslate.com/Clapper) on an Apple iPad. We used this method because GoPro cameras and other similar cameras do not support advanced time coding methods such as the Society of Motion Picture and Television Engineers format that assigns a unique time stamp to each video frame. This gave us greater flexibility in camera choice while still allowing excellent synchronization.

## Video Editing and Archiving

In addition to the cameras and mounts, we also needed the ability to review, edit, and back up the video files securely. As our video editing workstation, we chose a 27-inch Apple iMac with a 3.4GHz Quad Core Intel Core i7 processor, 16GB 1333MHz DDR3 SDRAM, an AMD Radeon HD 6970M 2GB GDDR5 graphics card, and a 1 TB hard drive (\$3,000). In order to ensure ample hard drive space while editing and rendering the large video files, we added a high speed 6 terabyte LaCie 2Big Thunderbolt series external hard drive (\$800) encrypted using Mac OS X Disk Utility. We used Final Cut Pro X software (\$300) to edit the video. We archived the video files on 20 TB of dedicated server space on the CHOP Research Institute Storage Area Network (SAN). We synchronized the footage from all cameras by aligning the video at the time marked by the clapperboard app. Within Final Cut, we muted all sound except for the monitor feed to enhance audio quality when reviewing. We then exported the video as a much smaller .mov file and uploaded it onto



Figure 3. Example of Alarm Video Review Interface, Viewed on a Computer Using Windows Media Player. Clockwise from upper left: the monitor screen, a close-up view of the patient, and a wide view of the room including the door and window.

the secure server for clinical expert review. The large Final Cut project files were backed up to the server and then deleted off of the external hard drive. An example frame from a final .mov file used for review is shown in Figure 3.

# Video Review and Annotation

To facilitate efficient video review of alarm events, we needed a tool to generate a time-stamped list of alarms that occurred during the video session so that we could use those as "bookmarks" when reviewing the hours of study video we captured. The hospital's Biomedical Engineering Department had a software application with that functionality already in place; it was in use primarily for evaluating the technical status of monitors throughout the hospital. Known as BedMaster Ex (Excel Medical Electronics, Jupiter, FL), this software "listens" to the GE monitor network, and records each patient crisis, patient warning, patient advisory, and system warning monitor alarm in a relational database. Patient message, system message, and system advisory alarms are not captured by BedMaster and were not included in our review. We also did not include non crisis alarm conditions that occurred while the "Alarm Pause" feature was activated but did not break through, as these conditions are also not captured by BedMaster.

Using this database, we had the ability to access the alarms occurring in any bed in the hospital in near real time and generate reports for the alarms occurring during each video session. We parsed the data included in each alarm report and, using the video start time, we calculated the video clip time when each alarm was triggered to serve as a bookmark. We then imported each alarm report into REDCap (Research Electronic Data Capture),<sup>26</sup> which housed our data entry forms for annotating each alarm. REDCap is a web-based database application designed to support the electronic collection and management of research data. We then reviewed the video by streaming it directly from the secure research SAN onto computers connected to the hospital network. A trained research assistant reviewed and annotated each alarm first. Expert clinical reviewers

then logged in and were presented with a queue of alarms to review, along with the video clip time so that they could jump directly to the alarms without having to sift through hours of footage. Disagreements between the research assistant and expert were noted in the database and resolved by consensus, with a third member of the research team consulted if necessary.

# Human Subjects Protection

In addition to the technical aspects of the project, there were a number of practical issues that arose related to human subjects protection. This study was among the first research projects approved by the Institutional Review Board (IRB) of The Children's Hospital of Philadelphia that proposed using video to evaluate patient safety. Therefore we needed to work closely with the to ensure that the necessary protections were in place, while ensuring that the study was feasible to complete.

# Consent and Assent

Patients, their parents/guardians, and nurses were all considered subjects in the study. We obtained written informed consent from the nurse and the parent/guardian of all patients who were video recorded. We were granted a waiver of assent for the patients due to the diminished capability of ill hospitalized children to provide assent.

# Confidentiality

All subjects who consented to participate were informed that they could request that we stop filming at any time if they became uncomfortable with the study. They were also informed that, at the end of the video recording period, they could request that we not use the video for research and destroy it immediately. In addition, we obtained a Certificate of Confidentiality<sup>27</sup> from the National Heart, Lung, and Blood Institute to further protect staff and families. With this certificate, we cannot be forced (for example by court order or subpoena) to disclose the video for use in any federal, state, local, civil, criminal, legislative, administrative, or other proceedings. Subjects were informed, however, that we would in all cases, take the necessary action and report to authorities any indication that

This study was among the first research projects approved by the Institutional Review Board (IRB) of The Children's Hospital of Philadelphia that proposed using video to evaluate patient safety. anyone captured on video attempted to cause harm to themselves or others.

#### Bystanders Captured on Film

We were granted a waiver of consent for non-subjects who may be captured on film inadvertently. This was justifiable because the study personnel agreed to never use the video files or other data for any purpose other than conducting the research, and no one outside the study team was given access to view the video files for any reason. To inform bystanders that video and audio recording was in progress in some areas of the unit, we mounted signs at entrances to the unit notifying anyone who enters that filming is underway, with the principal investigator's mobile phone number included.

Our initial IRB approval stipulated that we blur the faces of non-subjects. We found that the process of blurring was very time-intensive (up to 30 hours for experienced video technicians to blur the faces of all non-subjects in a six-hour video). The IRB determined that the study could not be practicably carried out if such effort was required to blur, and removed that stipulation in a subsequent protocol amendment.

Anticipating the possibility of failures, we included camera angles with overlapping fields of view, we checked on the cameras every one to two hours throughout the study period, and we numbered all pieces of equipment and meticulously documented failures so that we could eliminate faulty equipment.

#### Limitations of Video Method

We noted several limitations to this video method during its development, including challenges capturing the monitor display, camera failures, and the Hawthorne effect. In each case, we implemented mitigating measures to eliminate or minimize the threats of these limitations to the success of the video method.

#### Video Recording the Monitor Display

Our method involved using a camera to capture the physiologic monitor display. This resulted in adequate video quality for review. However, our original plan was to record a full-screen video feed obtained directly from a VGA output on the rear panel of the monitors, connected to a laptop computer using a VGA frame grabber (VGA2USB HR, Epiphan Systems, \$800). We abandoned this method because 1) the resulting video frame rate was inadequate, making the waveforms appear blurred, and 2) it required a laptop computer and the VGA device for each monitor, making it a much more expensive and less scalable approach than simply recording the monitor display with a camera.

#### **Camera Failures**

While the system was reliable the vast majority of the time, on a few occasions we encountered technical problems that led to camera failures. The root causes of the failures were found to be 1) poor physical connections between the camera and the power adaptor due to setup errors by staff, 2) use of power supplies with different voltages than recommended by the camera manufacturer, or 3) memory card corruption. Anticipating the possibility of failures, we included camera angles with overlapping fields of view, we checked on the cameras every one to two hours throughout the study period, and we numbered all pieces of equipment and meticulously documented failures so that we could eliminate faulty equipment. By following these procedures, we were able to avoid significant data loss.

#### The Hawthorne Effect

We fully acknowledge that some nurses in this study may have changed their usual behavior because they were being filmed, and may have been more responsive to alarms than usual. We suspect that Hawthorne-like effects<sup>28,29</sup> were minimal because 1) nurses are accustomed to the use of video in clinical care, for example, when patients undergo video electroencephalography sessions for seizure-like events, 2) the equipment was mounted unobtrusively in the rooms, 3) at the end of several studies, nurses reported having forgotten that they were being recorded, and 4) we occasionally observed nurses engaging in behaviors that might not be considered socially desirable while working (for example, reading from a novel).

We captured these observations in field notes. If there was a Hawthorne-like effect present, this would reduce the effect observed relative to the actual effect of alarm fatigue, biasing the results toward the null.

# Summary

We have outlined the development of a novel video method to study physiologic monitor alarms. To our knowledge, this is the first description of a method to measure physiologic monitor alarm response time as a proxy for alarm fatigue. Developing this method involved obtaining reliable equipment, implementing technically sound processes, and instituting extensive measures to protect human subjects. This method is highly scalable and adaptable to different care environments. We suspect that the description of our method will be useful to multidisciplinary teams interested in quantitatively evaluating physiologic monitor alarms and their associated responses in order to learn about alarm fatigue and other patient safety issues in clinical settings.

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# Contributors

Dr. Bonafide led the planning, conduct, and reporting of the work described in the article and is responsible for the overall content. All coauthors participated in the planning, conduct, and manuscript revision process. To our knowledge, this is the first description of a method to measure physiologic monitor alarm response time as a proxy for alarm fatigue. Developing this method involved obtaining reliable equipment, implementing technically sound processes, and instituting extensive measures to protect human subjects.

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