

Research

Acceptability, Feasibility, and Cost of Using Video to Evaluate Alarm Fatigue

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The factors that contribute to nurses' response time to physiologic monitor alarms are poorly understood. Nurses caring for hospitalized patients typically experience high rates of nonactionable alarms, which are thought to contribute to alarm fatigue. Proving the existence of alarm fatigue in the hospital and understanding the interplay among the numerous other factors contributing to alarm response time are complex challenges.

Video is a powerful tool to evaluate the quality of care delivered.¹ In 2014, members of our research group published an article describing the methods developed to use video to begin disentangling the wide range of factors thought to contribute to alarm response time.² Those methods have resulted in two projects. The first was a pilot project during which we recorded 210 hours of patient care and captured 5,070 alarms and responses.³ In that pilot, we demonstrated an association between higher numbers of nonactionable alarms in the preceding 2 hours—a proxy for acute alarm fatigue—and slower response time to subsequent alarms.³ In the second (current) project, we recorded 551 hours of patient care and captured 11,745 alarms and responses. This article describes the acceptability, feasibility, and costs of the second project.

Video offers the ability to gather a tremendous amount of insight into alarms and staff responses.

Our research group is frequently asked by clinicians, technicians, and alarm experts to describe the acceptability, feasibility, and cost associated with video-based projects. Video offers the ability to gather a tremendous amount of insight into alarms and staff responses, but analyzing video can be expensive and time consuming. In this article, we report the metrics used to describe the acceptability, feasibility, and cost of using video to evaluate physiologic monitor alarm characteristics and responses in our most recent study, which generated 100 video recordings averaging 5.5 hours each.

Methods

The study took place at the Children's Hospital of Philadelphia on a medical unit that cares for infants and young children with routine general pediatric problems and complex medical conditions. All patients in the study were monitored using General Electric Dash 3000 devices. A central monitoring display was at the nurses' station, but no staff were assigned to review alarms centrally. In addition to alarming at the bedside and the central station, alarms for asystole, ventricular tachycardia, ventricular fibrillation, apnea, heart rate, respiratory rate, oxygen saturation, probe off, and leads fail also automatically sent

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text messages to the bedside nurse using a secondary notification system. No alarm marquee systems were in use.

Eligible Patients and Nurses

All patients on the unit who were undergoing continuous cardiorespiratory and/or pulse oximetry monitoring were eligible for the study unless they were anticipated to either be discharged or have their monitoring discontinued during the video-recording period. Since participating required written, in-person consent from a parent, only patients with a parent present at the bedside could be consented. All nurses were eligible to participate if they were caring for an eligible patient.

Definitions

The following definitions were used in the study:

- Clinical alarm: An alarm for a physiologic parameter that is out of range or indicates cardiac arrhythmia.
- Valid alarm: A clinical alarm that correctly identifies the physiologic status of the

patient. Validity was based on waveform quality, signal strength indicators, and artifact conditions, referencing the monitor's operator's manual.

- Actionable alarm: A valid clinical alarm that 1) leads to an observed clinical intervention (e.g., initiating supplemental oxygen), 2) leads to an observed consultation with another clinician (e.g., discussing the patient's tachycardia with a physician) at the bedside, or 3) warrants intervention or consultation for a clinical condition (e.g., prolonged desaturation) that was unwitnessed (i.e., occurred while no clinicians were present and resolved before any clinicians entered the room or visualized the central monitoring station).
- Nonactionable alarm: An alarm that does not meet the actionable definition above, including invalid alarms (such as those caused by motion artifact), alarms that are valid but nonactionable, and technical alarms.
- Technical alarm: An alarm for a problem with the physiologic monitor device or associated sensors.



Figure 1. Example frame from video review window

- Alarm response time: The number of seconds elapsed between the start time of an audible alarm on the bedside monitor and the time a clinical staff member either entered the patient's room or viewed the central monitoring station.

Video Methods

The video methods have been described in detail previously.^{2,3} Briefly, to capture multiple angles while remaining minimally obtrusive to patients, family, and staff, we used temporarily mounted GoPro cameras placed in inconspicuous locations in patient rooms and on the central monitoring station.² Each video included five to seven camera views (Figure 1). When video recording during overnight hours, we also experimented with a Canon XA10 camera that featured a built-in infrared illuminator. Its low-light performance was excellent but rarely necessary, as nurses and parents often left lights on in the patient room overnight. In most cases, the ambient light was sufficient for the GoPro cameras to perform adequately.

Before setting up cameras, we obtained consent from both a parent of the patient, as well as the patient's primary bedside nurse. After obtaining consent from both parties, recording began prior to mounting the cameras, so that all cameras could be synchronized together. During setup, the research coordinator administered a questionnaire to the bedside nurse regarding their demographics, nursing experience, and knowledge of the patient. When all cameras were in place and connected to a power source, they would be left to record for approximately 6 hours with checks every 30 to 60 minutes to ensure they were still recording, attached to power sources, and properly positioned.

After 6 hours, we stopped recording and removed the cameras. We administered additional questionnaires to the parent and bedside nurse on their experience of participating in the study. Next, we uploaded the videos to a computer and compiled them into a synchronized single view displaying all camera views, then edited the footage. The complete video was then exported and uploaded to a secure server.

After the recording and editing processes were finished, videos were reviewed and annotated. To guide the annotation process, we used BedMasterEx v4.2.1 software (Excel Medical Electronics, Jupiter, FL) to obtain a time-stamped list of all alarms that occurred during the study period. All alarms, even those with overlapping durations, were included. We uploaded the list to REDCap⁴ and used an alarm report to generate a queue of alarms for review. During video review, researchers jumped to each alarm time based on the Bedmaster time stamp data and annotated information, including the type of alarm, if the alarm was valid and actionable, and how clinicians responded, according to the study definitions described above. Our research coordinator was intensively trained to assist in this process. Following a training period that involved supervised review and discussion of 4,675 clinical alarms, the research coordinator and principal investigator separately reviewed 883 clinical alarms. The research coordinator and principal investigator agreed on the validity determination for 99.3% and the actionability determination for 99.7% of alarms. Based on the strength of these results, for the remaining alarms, the principal investigator performed secondary review of valid clinical alarms only.

Acceptability Metrics

To measure the acceptability of the study from the perspectives of the parents we approached for consent, we first evaluated the number of parents who declined. We then analyzed the results of parent questionnaires completed at the conclusion of each video session. The parent questionnaire included the following items: 1) Did participating in this study change the way you interacted with your child? 2) Did participating in this study change the way you interacted with your nurse? 3) Did participating in this study change the way you interacted with your physicians or nurse practitioners? 4) Did participating in this study change the way you interacted with anyone else (such as other family members)?

To measure the acceptability of the study from the perspectives of the nurses who were approached for consent, we first evaluated the

number of nurses who declined. We then analyzed the results of nurse questionnaires completed at the conclusion of each video session. The nurse questionnaire included the following items: 1) Did participating in this study affect your ability to care for your patients? 2) Did participating in this study affect your interactions with patients/families? 3) Did participating in this study affect your interactions with other nurses? 4) Did participating in this study affect your interactions with physicians or nurse practitioners?

Feasibility Metrics

The three main factors contributing to feasibility were calendar time required to complete recruiting, necessary study team composition, and personnel effort required (measurable time spent working on the study).

We calculated calendar time to complete recruiting by identifying the date of the first and last patients enrolled, as we were recruiting every week in between those dates. We defined necessary study team composition as the minimum number of distinctly skilled team members required to complete the work. Personnel effort categories included research coordination, video recording and management, video review, study oversight, and analytic support.

The personnel effort (measurable time spent) on video review was extracted from the REDCap database used to annotate the videos. To calculate the time spent by each study team member, we used the logging module of REDCap, which lists all data entries and changes made to the project, along with time stamps accurate to the minute. We used this to identify video annotation data entry “blocks” of time spent by study staff. These data entry periods were defined as consecutive alarm entries for the same video without any gaps of 30 minutes or longer between two alarms (corresponding to a likely break or shift in tasks). This method of calculation was intended to include the time to switch between alarms during a block of reviewing a group of alarms but was not intended to include longer breaks (such as a lunch break). The number of data entry periods in a video was not limited; the start of a data entry period was either the first alarm in the video or the first

alarm after a break of 30 minutes or longer between alarms. The last alarm in a data entry period was either the final alarm in the video or the alarm that immediately preceded a break of 30 minutes or longer. For this analysis, we excluded the first 25 videos because the calculation method described above was not valid for the review workflow we initially used for those sessions. We randomly selected 20 of the remaining 75 videos for this analysis. Then, for each reviewer, we calculated the average time spent reviewing each alarm across all of the reviewer’s data entry periods. We reported the video review tasks based on the two main data entry forms used: 1) “Making valid and actionable determinations for each alarm” and 2) “Identifying alarm responders and measuring response time.”

The total personnel effort (measurable time spent) for other aspects of the study (e.g., screening, consenting, setting up the video) was estimated by the staff performing each task using time stamps from the electronic and paper study documents, when they were available.

We performed a data analysis that required input from a biostatistician and data manager/analyst. The time spent for each of these roles also was estimated.

Cost Metrics

To estimate the costs of the study, we identified the following cost categories: research coordination, video recording and management, video review, study oversight, analytic support, and equipment and storage costs. For each personnel cost, we multiplied the number of hours by the hourly rate for each individual plus a 25% fringe benefit rate. For the research coordinator and video engineer positions, we estimated \$20 per hour plus fringe. For the expert physician reviewer and biostatistician advisor positions, we estimated \$75 per hour plus fringe. For data management and analysis, we used the current rate for these services at our hospital’s Healthcare Analytics Unit: \$73 per hour (no fringe).

Results

We performed the study between July 22, 2014, and Nov. 11, 2015. To yield 100 usable

video recordings, we screened for eligible subjects approximately 3.5 days per week during that time from the inpatient medical unit described above.

Parent Acceptability

We approached the parents of 126 patients. Of those, 13 parents declined immediately and one parent initially consented but declined before video recording began (112 participants; 88% consent rate). The most commonly cited reason for declining was a desire to breast-feed without being video recorded.

For the four questions regarding whether participating in this study changed the way the parents interacted with their child, staff, or others, all 112 parents answered “no.”

Nurse Acceptability

All 38 nurses caring for the 112 patients who underwent video recording agreed to participate (100% consent rate). With respect to the four questions asked on the nurse questionnaire regarding whether participating in this study affected their ability to care for patients or their interactions with patients, families, or staff, one nurse said that participating in the study affected her interactions with a patient. This response resulted from the patient's parents requesting privacy when changing diapers, which required the nurse to either move the baby off camera or obscure views of the baby during diaper changes. No other nurses reported adverse effects in relation to their ability to care for patients or interact with patients, families, or staff.

Feasibility

Calendar time. The total calendar time to complete recruiting was 68 weeks, during which 126 parents were approached, 112 patients were enrolled, and 100 patients with usable video recordings were evaluated. For 12 of the 112 enrolled patients, failures of one or more cameras or memory cards rendered the video unusable.

The primary driver of the 68-week calendar time was a lower-than-expected availability of eligible patients who were not being discharged and were remaining on monitoring, with parents at the bedside for consent. As a result, we screened for eligibility on many days during which no patients were enrolled.

We chose to continue recruiting on the single unit, rather than expanding to many units, because we wanted to evaluate the same group of nurses across multiple sessions and determine whether the same nurses respond to alarms differently under different conditions. The estimated number of hours to perform study tasks is shown in Table 1.

Study team composition. To perform the study tasks, three roles were essential: 1) the principal investigator responsible for providing supervision and troubleshooting any challenges that arose; 2) the research coordinator responsible for screening, consenting, and administration of the study and for video review; and 3) the video engineer responsible for all aspects of video setup, recording, and management. On days when video recording could potentially take place, all three individuals had to be available in case an eligible subject consented to participate.

Total personnel effort (measurable time spent). The measurable personnel effort to complete the data collection is shown in Table 1, according to category. The principal investigator devoted 734 hours for expert review and study oversight, the research coordinator 1,292 hours for research coordination and video review, and the video engineer 1,344 hours for video recording and management.

Screening involved identifying patients on the unit each day who were eligible to participate per the criteria described in ELIGIBLE PATIENTS AND NURSES. This occurred 3 to 4 days per week, averaging 2 hours per day (Table 1).

After identifying patients eligible to participate, in-person consent was required from a parent, often involving waiting for the parent to be present, awake, and available (not already engaged in discussions with healthcare providers). When the parent was available, the consent form had to be reviewed, discussed, and signed. The bedside nurse also had to be consented, involving time spent waiting until the nurse could review and sign the forms and respond to the questionnaire. After consent was obtained, the forms had to be scanned, then locked in a secure cabinet. On days that a recording took place, these tasks averaged an additional 4 hours per session (Table 1).

Features

Item	Description	Total Cost (\$)
Research coordination		22,525
Screening	2 hours/day, 3.5 days/week for 68 weeks	11,900
Consenting	1 hour/session, 126 sessions attempted	3,150
Administering questionnaires	1 hour/session, 112 patients underwent video recording	1,875
Record keeping and administration	2 hours/session, 112 patients underwent video recording	5,600
Video recording and management		33,600
Camera setup, recording, take down, memory card management	9 hours/session, 112 patients underwent video recording	25,200
Importing, processing, and editing video files	3 hours/session, 112 patients underwent video recording	8,400
Video review and annotation		27,588
Making valid and actionable determinations for each alarm	54 seconds per alarm, 11,745 alarms reviewed	4,400
Identifying alarm responders and measuring response time	66 seconds per alarm, 11,745 alarms reviewed	5,375
Expert review by principal investigator	132 seconds per alarm, 5,177 alarms reviewed	17,813
Study oversight		51,000
Training, supervision, and regulatory tasks performed by principal investigator	8 hours/week for 68 weeks	51,000
Analytic support		12,805
Biostatistician consultation	12 hours total	1,125
Data management and analytic services	160 hours total	11,680
Equipment and storage		24,032
Cameras	12 GoPro cameras	4,800
Mounts	Assorted camera mounting devices	1,000
Editing workstation	27-inch iMac with upgraded memory and graphics card	3,000
External hard drives for video backups	Six Lacie 6-TB Thunderbolt drives	2,700
Lockable equipment cart	One Harloff five-drawer mini line anesthesia cart	1,000
Memory cards	20 64-GB high-speed camera memory cards	600
Chargers, cables, and extra batteries	One charger, cable, and extra battery for each camera	840
Video-editing software	One copy of Final Cut Pro X	300
Server space (without redundancy)	8 TB of institutional server space at \$51/TB/month for 24 months	9,792
Total		171,550

Table 1. Costs associated with using video to evaluate physiologic monitor alarms and responses

After acquiring the video, we imported, processed, and edited the files for review. Because we were compressing multiple high-definition video feeds into one screen, exporting the completed video was a time-consuming process. Typically, export time was approximately equivalent to the duration of the video (5–6 hours). We began exporting videos at the end of the work day so that the process would be complete by the next morning. For this reason, we did not include video export time in the total person-hours required per video.

We analyzed alarm data from the 20 randomly selected sessions (total of 2,177 alarms) to determine the average time spent reviewing and annotating each alarm, including the time required to switch between alarms (Table 1). Making valid and actionable determinations for each alarm took an average of 54 seconds per alarm. Identifying alarm responders and measuring response time took an average of 66 seconds per alarm. These averages were multiplied by the total number of alarms (11,745) to estimate total time spent on review and

annotation. Expert review and annotation required an average of 132 seconds per alarm, with fewer than one-half of the alarms reviewed (5,177) requiring expert review.

Cost

To accurately report the costs of performing the study, we included the research coordination, video recording and management, video review, study oversight, analytic support, and equipment and storage costs in Table 1, including the fringe benefit rates (when applicable).

The total cost of the study was estimated to be \$171,550, or \$311 per recorded hour of video. Some costs were fixed, such as equipment and analytic support. Others varied by the number of days we operated the study, then by the number of days we screened for eligible patients, number of video recordings performed, or number of alarms reviewed. Teams planning to undertake a video review project should consult the costs in Table 1 to customize the fixed and variable estimates for their specific needs, as the budget will vary considerably based on sample size and study duration. In addition, because the research coordinator and video engineer were engaged in other active projects, we did not need to include “standby time” for days when video recording was planned but no eligible patients were available.

Discussion

For evaluating alarm validity, actionability, and response time, video offers an unparalleled perspective but comes at a substantial cost. The main findings of this study were that video recording of monitor alarms and responses were 1) highly acceptable to participating nurses and parents; 2) feasible to complete using a core team of principal investigator, research coordinator, and video engineer; and 3) too expensive and time intensive to complete on a “shoestring budget,” yet not beyond the reach of a budget that factors in an external grant or a substantial institutional financial commitment.

Few other studies have examined the acceptability, feasibility, and cost of using video to evaluate the quality and safety of care delivery. In a survey of 154 parents at a single children’s hospital in Canada, more than 90%

of parents rated video recording of patient care acceptable for healthcare research, medical education, quality improvement, and patient safety purposes.⁵ Siebig and colleagues^{6,7} have described in-depth video annotation methods to evaluate alarms occurring in intensive care units but have not reported in-depth acceptability, feasibility, and cost metrics. Surgical teams have reported the feasibility of using point-of-view cameras in the operating room using various techniques but have not addressed acceptability or costs beyond the cost of the cameras.^{8–10}

The main findings of this study were that video recording of monitor alarms and responses were 1) highly acceptable to participating nurses and parents; 2) feasible to complete using a core team of principal investigator, research coordinator, and video engineer; and 3) too expensive and time intensive to complete on a “shoestring budget,” yet not beyond the reach of a budget that factors in an external grant or a substantial institutional financial commitment.

As one approach to providing rapid video audit and feedback for hand hygiene compliance and operating room safety and efficiency, investigators at a New York hospital partnered with a third-party remote video auditing company (Arrowsight) and effectively outsourced video management and review. This approach offered the advantage of real-time auditing of clinical care by remote staff managed completely by the third-party company.^{11–13}

Given that video recording is performed in the majority of operating rooms, intensive care units, and neuroepilepsy units in North American and British pediatric hospitals,¹⁴ considerable opportunity exists for secondary use of video data already collected during the delivery of care to evaluate and improve the quality and safety of care. Some hospitals have taken the approach of repurposing video recorded for clinical purposes (such as video from laparoscopy¹⁵ or polysomnography¹⁶) to evaluate quality and safety—an approach that is much more cost efficient than generating video de novo. This secondary use approach also offers the advantage of substantial cost savings. For example, if the costs of video equipment, screening, consent, administering questionnaires, camera setup, and video

management were eliminated from the current study, the cost per recorded hour could be reduced by nearly one-half.

Limitations

The current analysis involved a few limitations. First, we estimated costs as accurately as possible, acknowledging that personnel costs vary at different institutions. By providing the time estimates and transparent cost calculations, we hope that the information will be applicable to others interested in using video to study patient safety, even if the final costs differ. Second, to provide generalizable costs, we included the analytic support and server space estimated costs using our institution's rates, even though the services were provided to us without charge (biostatistician consultation and server space) or performed by the principal investigator (data management and analytic services). Third, we did not include costs for equipment items that were purchased but not ultimately used in the study. These items either did not work as well as those reported or were deemed unnecessary after experimentation (such as the Canon XA10 camera with infrared illuminator). We hope that providing a detailed list of the equipment used will save future investigators time and effort. Fourth, we did not have a reliable method to obtain alarm response time data for nurses who were not being observed on video; therefore, we cannot determine the Hawthorne effect induced by video recording. Fifth, our actionability definition was very clinically oriented and the determination was based largely on clinical behavior. Therefore, in some situations, interventions may have been performed unnecessarily. Future studies should consider performing a blinded secondary review of the alarm and waveform data only, without the video.

Conclusion

Video recording is a highly acceptable and feasible tool to evaluate quality and safety in the hospital. At a cost of more than \$300 per hour to capture, manage, and review the

recordings, our project was expensive. Video recording should be used selectively for situations in which it can provide insights into care that are not available using other methods. When available, the secondary use of video already collected during the delivery of care can offer the ability to gain similar insights into quality and safety without the high costs of coordinating the study or managing the video. ■

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