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Medical Alarms: Critical, Yet Challenging

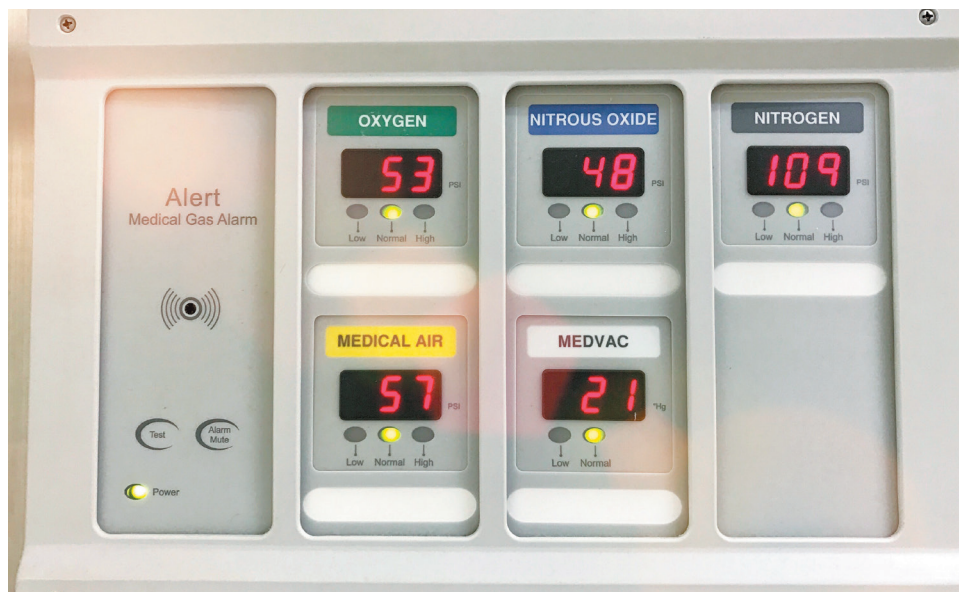
by Kendall J. Burdick, MD; Nathan Taber, MD; Kimberly Albanowski, MA; Christopher P. Bonafide, MD, MSCE; and Joseph J. Schlesinger, MD, FCCM

INTRODUCTION

Ensuring patient safety during surgical procedures remains at the forefront of quality improvement initiatives, as supported by APSF. In addition to administering and monitoring anesthesia, clinicians manage patient vital signs and overall well-being throughout the surgery, often in a very distracting environment.¹ This is only made possible with the crucial help of medical alarms. These alarms are designed to alert the clinician and other medical staff to changes in patient vital signs, such as a drop in blood pressure or a decrease in oxygen saturation. However, clinicians often need to filter out the extraneous stimuli of the operating room to recognize and respond to these alarms. There are many disturbances that can draw the clinician's attention away from the patient, including equipment delays, personal conversations, and pager/electronic device use.¹ Furthermore, without the added confirmation of the patient's subjective experience, clinicians must rely strictly on the data presented by the monitor, highlighting the importance of accurate and clinically actionable alarms. Medical alarms are an essential component of the clinician's toolkit and help to ensure the safety of patients undergoing surgical procedures.

Alarm fatigue occurs when a user becomes desensitized to alarms due to excessive, non-actionable or invalid alarms, ultimately resulting in a delayed or no response.^{2,3} Alarm fatigue contributes to missed alarms and medical errors resulting in death, increased clinical workload and burnout, and interference with patient recovery—making it a safety issue that spans clinician to patient.⁴ The multifaceted approach to alarm fatigue should include consistent equipment, delaying alarm activation, and reducing alarm volume.² In this article, we highlight the continued need for patient safety, and recent clinical and engineering advances in mitigating alarm fatigue.

Alarms are made to alert staff to a significant clinical change or a required action, though many can be nonactionable or invalid. Nonactionable alarms are alarms that require no action by the clinical care team and have been measured to comprise up to 85% of clinical alarms.⁵ In addition to nonactionable alarms, alarm fatigue can result from frequent invalid alarms.⁶ Invalid alarms occur due to device artifact or error, such as an electrocardiogram reporting ventricular tachycardia when the



patient is actually in sinus rhythm and has a loose electrocardiogram lead. Invalid alarm rates have been measured to range from 85% to 99.4% of all clinical alarms.⁷ When alarms are consistently nonactionable or invalid, the priority for a user to respond may be lost or replaced with exasperation, accumulating in desensitization and dissatisfaction among health care staff.⁸ While individual personality traits and workload are not easily modifiable, alarm tones and thresholds are, making alarm research and innovation the key to decreasing alarm fatigue and desensitization.

These various factors converge to exacerbate alarm fatigue and subsequent effects of nonoptimal medical alarms. Fortunately, there are efforts underway from safety organizations, clinical workflow, and engineering innovations to prevent and combat these workplace and patient risks.

PATIENT SAFETY

The APSF recommends the use of medical alarms to help improve patient safety and reduce the risk of adverse events during the administration of anesthesia and perioperative period.⁹ Similarly, the American Society of Anesthesiologists Equipment and Facilities Committee (of which author, Joseph Schlesinger, is a member) prioritizes workplace safety and plans to release an "Alarm Position Statement" in late 2023. Additionally, addressing alarm fatigue and alarm impact on patients has been a focus for safety regulatory bodies.

Alarm fatigue has been named a Top 10 safety priority for The Joint Commission every year since 2013.¹⁰ ECRI (originally founded as the Emergency Care Research Institute) has named missed alarms and alarm overload as a "Top 10 Health Technology Hazard" every year from 2012 to 2020.¹¹ In 2011, the Association for the Advancement of Medical Instrumentation (AAMI) held a Medical Device Alarms Summit focused on alarm challenges, patient safety, and alarm research. Since then, AAMI has provided a variety of webinars and research grants to support the investigation and innovation of alarm fatigue prevention.

These patient safety-focused organizations remain dedicated to the improvement of the clinical environment, with a primary focus on innovating medical alarms. As a result of their dedicated safety initiatives and through the efforts of researchers around the globe, numerous advancements in medical practice and alarm design have been accomplished and are still underway.

CHANGES TO WHEN ALARMS SOUND

An effective adjustment to clinical alarms has consisted of individualizing alarm parameters² to increase precision. Individualizing parameters consists of modifying the threshold of an alarm to reflect an individual patient's physiologic status as compared to an unmodified default clinical alarm setting. Adjustments include alarm threshold tightening, adding

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Multisensory Alarms Provide Alerts Using Different Senses, Such as Sound, Light, and Vibration,

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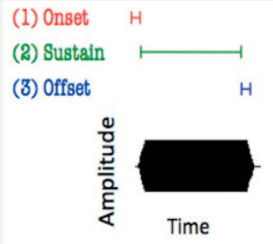
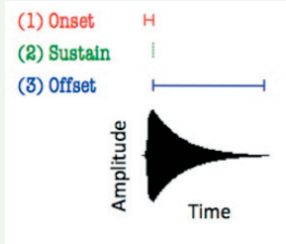

delay periods between detection and alarm, disabling nonactionable alarms, and adjusting volume based on priority. These adjustments have been shown to reduce alarm rates (specifically nonactionable)¹² and perceived workload.¹³ Evidence-based software has been developed to assist in safe and effective personalized thresholds. For example, Halley Ruppel, PhD, RN, and colleagues utilized and evaluated the impact of an alarm parameter customization software in an ICU.¹⁴ They found that the alarm parameter customization software significantly reduced the number of alarms by up to 16%, and the duration of alarms by up to 13%. This key study has shown that alarm parameter customization can have a profound impact on the alarm atmosphere and function in a hospital, especially for clinicians who frequently respond to alarms.

CHANGES TO HOW ALARMS SOUND

In addition to adjusting when an alarm sounds, innovating how an alarm sounds is an opportunity to make them more learnable, communicative, and tolerable. For anesthesia professionals, alarms are frequently concurrent and occur during procedures that require visual attention, making the need to have clear and communicative alarms critical.

In 2006, the International electrotechnical commission (IEC) established an international standard for medical alarms 60601-1-8.¹⁵ However, alarms that abided by the IEC 60601-1-8 were difficult to learn and distinguish from concurrent alarms, as they used the same melodic structure, offering little individualizing detail between simultaneous alarms.^{16,17} As a result, a group of researchers created auditory icons as an alternative to the standard auditory alarms. Auditory icons mimic and/or represent the parameter that they are monitoring. For example, instead of the monotone beeping of a standard heart rate monitor, an auditory icon sounds like the “lub-dub” of a heartbeat (Table 1, [additional IEC icons available for listening](#)). These auditory icons were found to be easier to learn and more localizable than the traditional alarms tested.¹⁸ During clinical simulations, participants performed better when using auditory icons, including the ability to discriminate between simultaneous alarms and to identify alarm type.¹⁹ As a result of this strong supporting evidence, the IEC updated the 60601-1-8 in 2020 to include auditory icons as a supported medical auditory alarm.²⁰ By incorporating auditory icons, alarm systems can optimize their notification designs in an evidence-based manner.

Table 1: Comparison of Traditional vs Novel Alarm Design.

Category	Traditional alarm	Novel alarm
Auditory Icons	Tonal Alarm: Simple melodic structure 	Auditory Icon: Mimics physiologic structure 
Amplitude Envelope	Flat Envelope ²⁸ : Quick onset, quick offset 	Decaying Envelope ²⁸ : Quick onset, gradual offset 
Multisensory alarm	Tonal Alarm (as above)	Visual display of multisensory Apple Watch, with vibration and auditory alarm ²⁵ 

In addition to alarms being difficult to discriminate, annoyance with the alarm sound itself has also been documented as a contributor to alarm fatigue in clinicians.²¹ Amplitude envelope describes the “structure” of a sound—where a flat envelope (that of a typical alarm) would have a quick onset and offset, a decaying envelope (such as the noise of clinking wine glasses) has a quick onset, followed by a gradual alarm decline (Table 1). The literature has shown that using a decaying amplitude envelope significantly reduces alarm annoyance without interfering with learning or performance—while also preserving an alarm’s melodic and rhythmic structure.^{22,23}

Even simpler than re-engineering the auditory alarm structure, decreasing the volume at which an alarm is delivered has shown great benefits. At baseline, hospitals are noted to regularly exceed the World Health Organization’s recommendations for the clinical environment volume; however, alarms delivered at lower volumes may still elicit similar accuracy of alarm identification. One study found that par-

ticipant performance in interpreting and responding to patient crises had a minimal difference when an alarm was delivered at a volume 11 dB below the background noise, compared with the typical 4 dB above background noise.²⁴ Furthermore, devices, such as the Dynamic Alarm Systems for Hospitals, or D.A.S.H., have been developed and patented to regulate alarm volume based on the surrounding noise level.^{25,26} These systems provide important benefits to improve the auditory environment’s saturation with unnecessarily loud alarms.

Traditionally, medical alarms have relied primarily on the auditory sense, with partial notification through visual stimuli, such as a monitor. Multisensory alarms provide alerts using different senses, such as sound, light, and vibration, making them more noticeable in a busy operating room environment. Using multiple senses allows clinicians to respond to changes in a patient’s condition more rapidly and take appro-

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Integration of Multisensory Alarm Devices Is Feasible and May Improve Patient Safety

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appropriate action, improving patient safety and outcomes. Multisensory alarms also provide the opportunity to use wearable notification systems, such as an ankle band or smart watch (Table 1). When combining tactile (similar to vibration), visual and auditory stimuli into a wearable smart watch, undergraduate participants showed better accuracy, reaction time, and decreased mental workload in feasibility studies.²⁷ Studies are currently underway with clinical end-users to confirm the workflow and performance benefit. Based on these and more studies, integration of multisensory alarm devices is feasible and may relieve the auditory burden of the medical environment and increase the overall quality of care and patient safety.

Research and engineering teams dedicated to the modernization and innovation of medical alarms through auditory icons, adjustments to alarm character, and use of multisensory devices are crucial contributors to the prevention of alarm fatigue.

CONCLUSION

Anesthesia professionals play a critical role in monitoring a patient's vital signs and adjusting the anesthetic care as needed to ensure the patient remains in a safe and stable condition. They are also trained to respond quickly to medical emergencies that may arise during a procedure. Both roles require medical alarms to be safe and effective. This constant vigilance is essential to ensuring the best possible outcomes for patients undergoing medical procedures, making alarm design and optimization critical.

Patients in all medical settings rely on clinicians to care for and react to all their medical needs. Currently, the demanding workplace environment challenges staff with suboptimal alarm technology, contributing to alarm fatigue and burnout. By focusing on patient and provider safety, clinical workflow, and alarm technology, researchers, and policy makers can transform the medical alarm realm into one that is evidence-based and personnel-focused.

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