Redesigning Hospital Alarms for Reliable and Safe Care

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"Even the boy who cried wolf was right about the wolf once."

—Sherry Thomas

Introduction

Noise levels in hospitals have been rising for decades and are far higher than guideline values established by the World Health Organization. Alarms contribute significantly to noise pollution in healthcare facilities. Alarm safety is one of healthcare's most high-profile and intractable problems. A phenomenon known as "alarm fatigue," including limited capacity to identify and prioritize alarm signals, has led to delayed or failed alarm responses and deliberate alarm deactivations. Alarm fatigue has been implicated, according to federal agency reports as well as in the lay press, in patient morbidity and deaths, some highly publicized. Between 200 and 566 patient deaths have been reported to have died from 2005 to 2014 as a result of alarm mismanagement; these numbers are likely to be underestimates.[1] Many factors contribute to alarm fatigue, but perhaps most significant is a reported false alarm rate of as high as 90 % among millions of alarm signals. These large numbers of clinically irrelevant signals directly contribute to staff desensitization. In addition, high background noise levels in critical care and variable acuity units and in operating rooms contribute to alarm response failures. They do this by further increasing the cognitive load on staff; escalating distraction and irritability; and complicating discernment, attribution, and communication.

If, however, alarms are intended to maintain a level of situational awareness, designers need to engineer monitoring devices able to do some or all of the following: distinguish artifact from real patient status changes, determine whether these changes are contextually important, convey the source of the alarm to the receiver, and allow prioritization when operational attention is directed elsewhere (e.g., during line placement) or when multiple alarms sound.

Multiple levels of influence and opportunities for system intervention and innovation exist to facilitate timely and reliable alarm responses. These include addressing the broader acoustic context, clinician responsibility, deployment and

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[1] ECRI Institute. ECRI Institute releases top 10 health technology hazards report for 2014. November 4, 2013. https://www.ecri.org/Press/Pages/2014_Top_Ten_Hazards.aspx Accessed January 3, 2014.

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teamwork training, threshold-setting guidelines, improved user interfaces, and algorithms balancing alarm specificity with sensitivity. Monitoring devices that process complex data streams should produce clinically relevant alarm signals in an environment which is optimized for discernment and attribution and with user interfaces designed for timely interpretation, prioritization, and prompt action. Hospitals need a system-wide alarm management policy and protocols that define the alarm management strategy for alarmed medical equipment, and delineate how caregivers/nurses should respond to alarm conditions and signals.[2] Involving patients in the redesign of hospital acoustic environments may also improve patient experiences and satisfaction with their hospital care.

The Detrimental Impact of Noise and Alarms on Patients and Providers

Noise and sound characteristics have been demonstrate to negatively impact both patients and clinicians. In the 150 years since Florence Nightingale wrote about the adverse effects of noise on hospital patients, others have noted the problem, but it is still not recognized as a major cause of harm.

Hospital noise is considered pandemic, dangerous, annoying, and consistently leads to the lowest average HCAPHS (Hospital Consumer Assessment of Healthcare Providers and Systems) scores and is the lead patient safety goal for the National Patient Safety Foundation and The Joint Commission.[3] Critical, and less well understood or appreciated, is that the quality (characteristics) of the physical environment of sound, more than simply its volume (collectively, the "soundscape"), is significantly detrimental to the delivery of medical care and the well-being of both medical staff and patients. It directly contributes to medical error and patient harm.

Hospital noise routinely exceeds international WHO noise acceptable standards and is more than just an annoyance [1]. The World Health Organization (WHO) established hospital noise guidelines in the 1999 publication "Guidelines for Community Noise" to better understand and address the negative effects of noise, stating that perception of sounds is of major importance for human wellness [2]. According to WHO, excess noise can result in impairment of functional capacity or an impairment of capacity to compensate for stress. The WHO recommended a hospital sound level maximum (Lmax) of 40 decibels (dB) and 35 dB for patient rooms. Current hospital noise levels significantly exceed these numbers by an average of 30–40 dB [3]. Hospitals historically have not conformed to recommended or legislated sound levels [4]. It is not unusual for Emergency Departments, operating rooms (ORs), and intensive care units (ICUs) to have average noise levels in the 73–77 dB range with paging and surgical equipment producing intermittent noise spikes of over 90 dB [5, 6]. Consequently, noise in healthcare environments is becoming recognized as a serious health issue, increasing staff stress and absenteeism, hindering patient healing, and causing patient injury and even death [7, 8].

A growing body of research about the harmful effects of noise in the healthcare environment along with the new financial and regulatory incentives has advanced noise control in healthcare facilities to a top priority. High noise levels in trauma units can also detrimentally affect short-term memory tasks, mask task-related cues, impair auditory vigilance (for instance, the ability to detect and identify alarms), and cause distractions during critical periods [9]. A review of the literature by Ulrich et al. found more than 1200 studies linking the physical environment to patient and staff outcomes in areas of stress, fatigue, patient safety, outcomes, costs, and overall healthcare quality [10]. Dickerman et al. also found a direct link between patient care quality, patient health outcomes, and hospital design, supporting the link between hospital environments as a promoter of stress for patients and staff [11].

Poor acoustic clinical environments are also associated with an excessive cognitive load on clinicians [12] and interference with speech and communication, both of which can increase the

[2]See Johns Hopkins Hospitals clinical alarm management policy http://hpo.johnshopkins.edu/hopkins/policies/39/11305/policy_11305.pdf?_=0.231088243942.

[3]http://www.jointcommission.org/assets/1/18/jcp0713_announce_new_nspg.pdf.

risk of medical errors and patient harm [13, 14]. As an example, alarm fatigue, the clinician desensitization to incessantly beeping alarms amounting to hundreds of alerts a day (up to 90 % false or not relevant) is a national problem blamed for dozens of deaths each year, as overwhelmed staff do not respond or fail to respond with urgency [15]. Caregivers must exert greater effort to maintain accuracy which, in turn, increases physiological responses and fatigue [16]. Busch-Vishniac found noise levels at John Hopkins University Hospital were high enough to affect speech comprehension (speech intelligibility) [1]. Reduction in speech comprehension is also known to increase performance errors. Murthy and Rataplan found noise levels interfered with attending and resident interactions in more than a third of shift-change communication [6, 17]. Excessive noise levels can induce and exacerbate anger, annoyance, displeasure, and staff burnout [18]. Excessive noise is a stressor to both patients and staff. While researchers have noted improved patient outcomes and staff satisfaction in hospitals with perceived good acoustic environments, the reverse has also been demonstrated [19, 20]. Babisch's work illuminates the physiological effect of the noise–stress relationship. The impact of noise on medical errors and patient harm is summarized in Table 17.1 [21].

In addition to documented cardiovascular responses to stress, there are long-term health effects for individuals exposed to noisy environments. Excessive noise causes problems with concentration, fatigue, uncertainty and lack of self-confidence, irritation, misunderstandings, decreased working capacity, problems in human relations, and optimal decision integrity [22]. More studies to understand these ill effects will require transdisciplinary work using more sophisticated methods, tools, and techniques.

Table 17.1 Impact of noisy healthcare facilities on patients and providers

Medical errors
Impaired communication and concentration
Disorientation and distraction
Elevated blood pressure and stress levels
Auditory habituation or ear fatigue
Rule breaking behaviors (such as turning off alarms)
Sleep disruption and loss of sleep that is essential for healthy recovery
Startle response

Like many innovations, alarms were first developed as safety devices for an exceedingly small group of high-risk patients. Because clinical events and hemodynamic alterations often presage harm in this population, alarms have been highly successful at averting complications. Encouraged by these benefits, the medical community expanded this model to lower risk populations. Moreover, innovations in bioengineering and computer science have successfully embedded all types of alarms into an expanding portfolio of physiologic monitoring equipment with variable impact on patient care. The consequence of this well-intentioned technological evolution and generalization is epitomized in the din of chirps, beeps, bells, and gongs that typify hospitals today. It is, thus, not surprising that concerns regarding safety have emerged, even in populations for whom these protective devices were once considered most valuable.

Characteristics of Systems and Risk Management Framework

A surgical healthcare system includes several subcomponents. Foremost among these are those surgical or clinical processes, which are used to treat patients directly. Another component is technology, medical and nonmedical including information systems, diagnostic systems, imaging systems, as well as mundane technologies such as floor cleaning equipment, supply ordering, and distribution technologies [23]. Additionally, there is organization, the administrative arrangement that includes policies, procedures, strategies and tactics, management tools, business plans, etc. Providers are another subsystem. They include professional, technical, administrative, management, patient, public, government, and others. Finally, there is the physical environment including the architecture, engineering, interior design, and other environmental conditions which, in aggregate, impact a large number of organizational characteristics [24].

Charles Perrow studied major accidents and discovered that systems, rather than individuals, were often at fault [25]. Perrow and James Reason have redefined how we should understand the causes of accidents and how we fix problems [26]. One of Perrow's contributions was to describe how the components of systems are interrelated. He defined two dimensions, complexity and coupling, which predict how systems function. There are many other subcomponents of systems, some of which are hidden, and require "operators" to use a great deal of short-term memory, cognitive work, or computing power. The planning, designing, and construction of healthcare facilities involve physical structures and processes that are tightly coupled in that there is no "wiggle room" in the connections. If one component fails, the adjoining components are immediately impacted, sometimes in unforeseen ways.

Noise engineers and medical personnel generally have been working separately on noise issues, with limited progress and implementation of their findings. With increased urgency for quality and performance improvement, multidisciplinary teams have been formed to produce actionable research and evidence-based design initiatives [27]. This collaboration between medicine and engineering has produced data on physiological responses, healthcare outcomes, and economic impact, which have considerable influence on policies relating to noise, in contrast with the historic assumption that noise is nothing more than an annoyance.

Human Factors and Situation Awareness in Understanding Optimal Alarm Management

Human factors (also known as ergonomics) is the study of human interactions with tools, devices, and systems with the goal of enhancing safety, efficiency, user satisfaction, interpretability, and ease of action [9]. Nearly half a century of research and hands-on experience have produced a substantial body of scientific knowledge about how people interact with each other and with technology [28]. These "performance shaping factors" must be understood and incorporated in alarm design to enhance provider responsiveness [29]. For example, current medical device interfaces should be able to minimize false alarms produced by irrelevant signals such as patient repositioning, suctioning, and oral care, which can alter heart and respiratory rates, as well as dislocating sensors.

Human factors research is of great relevance in designing spaces for managing surgical patients and intensive care patients [30] and in considering the impact of the many "performance shaping factors" that can degrade human capabilities (Table 17.2). One of the most important decision-making skills by healthcare teams is to decide which sources of streaming information to devote attention to and what can wait. Where data overload is the rule and the patient's status changes continually, the ability to recognize clinical cues quickly and completely, to detect patterns, and to set aside distracting or unimportant data can be lifesaving. Situation awareness (or situation assessment) is a comprehensive and coherent representation of the (patient's) current state that is continuously updated based on repetitive assessment [31].

Situation awareness appears to be an essential prerequisite for the safe operation of any complex dynamic system. In the case of healthcare, establishing and maintaining a "mental model" of the acute patient and the surrounding environment including facilities, equipment, and personnel are essential elements to effective situational awareness [32]. Successful team situational awareness requires constant communication that enables members to converge around a shared mental model of the situation and a course of action to quickly correct course as needed. Effective teams adapt to changes in task requirements, anticipate each other's actions and needs, monitor the team's ongoing performance, and offer constructive feedback to other team members [33]. When team members share a common mental model of the team's ongoing activities, each may "instinctively" know what each of their teammates will do next (and why) and often communicate their

Table 17.2 Performance shaping factors affecting surgical care[a]

Individual factors	Clinical knowledge, skills, and abilities
	Cognitive biases
	Risk preference
	State of health
	Fatigue (including sleep deprivation, circadian)
Task factors	Task distribution
	Task demands
	Workload
	Job burnout
	Shiftwork
Team/communication	Teamwork/team dynamics
	Interpersonal communication (clinician–clinician/ clinician/patient)
	Interpersonal influence
	Groupthink
Environment of care	Noise
	Lighting
	Temperature and humidity
	Motion and vibration
	Physical constraints (e.g., crowding)
	Distractions
Equipment/tools	Device usability
	Alarms and warnings
	Automation
	Maintenance and obsolescence
	Protective gear
Organizational/cultural	Production pressure
	Culture of safety (vs. efficiency)
	Policies procedures documentation requirements
	Staffing cross coverage
	Hierarchical structure
	Reimbursement policies
	Training programs

[a]Modified from Barach, P., Weinger, M. Trauma Team Performance. In: Trauma: Emergency Resuscitation and Perioperative Anesthesia Management., Vol 1, Wilson, W. C., Grande, C.M. Hoyt, D.B. (Eds.), Marcel Dekker, Inc. 2007, 101–113. NY. ISBN: 10-0-8247-2916-6

intentions and needs nonverbally (sometimes referred to as implicit communication) [34].

Medical Device Features

Medical device alarms are deliberately designed to alert attention [35]. They can make the difference between timely, lifesaving interventions, and serious injury or death. Physiologic monitors, ventilators, infusion pumps, and many other medical devices contain clinical alarms to alert caregivers to critical events and to keep patients safe [36].

Monitoring devices that process complex data streams should produce clinically relevant alarm signals in environments optimized for discernment and attribution and contain user interfaces designed for timely interpretation, prioritization,

and prompt action. Addressing alarm fatigue requires that regulators, manufacturers, and clinical leaders recognize the importance and context of human factors and staff behavior, with design and evaluation of devices accomplished through clinical simulations [37]. In simulations, however, most of the noises are false alarms or don't require action [38]. The ventilator sounds a warning because a patient coughs. The infusion pump beeps after running out of a medication the patient no longer needs. The blood pressure monitor goes off after a nurse adjusts a catheter in the patient's artery.

Excessive numbers of alarms—particularly alarms for events that aren't clinically significant or that could be prevented from occurring in the first place—can lead to fatigue or worse ignoring the alarms as a form of tuning out, an unintended consequence of alarms, and ultimately patient harm [39]. Alarm fatigue, a condition which can occur in any hospital, is usually not caused by a single device but rather to the cacophony of noises and aggregate conditions under which alarms occur [40]. Alarm fatigue results in confusion and stress resulting from loud and conflicting signals which can lead to dangerous, life-threatening decisions, and behaviors [41]. Under these conditions, caregivers can easily become overwhelmed and are unable to respond to any alarm or to distinguish among simultaneously sounding alarms. They can become distracted, with alarms diverting their attention from other important patient care activities. Moreover, caregivers can become desensitized, possibly missing an important alarm because too many previous alarms have "cried wolf" (proved to be insignificant) [42].

In contrast to alarm fatigue, patients can also be at risk if an alarm does not activate when it should, if the alarm signal is not successfully communicated to staff, or if the alarm is ambiguous as to the source or severity of physiologic derangement, that is, does not provide sufficient information about the alarm condition. Additionally, when the caregiver who recognizing a signal as a valid alarm is unable to respond or is unfamiliar with the proper response protocol, patients do not benefit from the value of these technologies [43]. In short, any circumstance that results in the failure of staff (1) to be informed of a valid alarm condition in a timely manner, or (2) to take appropriate action in response to the alarm, can be considered a clinical alarm hazard [44].

Improving the acoustic environments for hospitalized patients can have significant positive effects on patients including decrease rehospitalization rates, improve sympathetic arousal in patients, and raise patient satisfaction as compared with noisy hospital environments [45]. Reduced noise was the most common item reported by hospital executives as a way to improve Patient-Reported Outcomes Measures (PROM) [46]. Almost 90 % of these executives believed that the primary benefit for patients was better sleep to help patients recover faster (75 %) and improve stress/anxiety (67 %).

Source–Path–Receiver Model

A simple approach to analyzing noise in surgical areas is by considering three basic elements: the sound source, the conveying medium, and the receiver (see Fig. 17.1) [47]. The most appropriate solutions then require alteration or modification in any or all of these three components. For instance: (a) to modify the output from source of the noise, (b) to alter or control the sound path to reduce transmission to the recipient, and (c) to provide the receiver with personal protective devices. This cross-disciplinary approach can provide detailed insights into addressing hospital noise and alarm fatigue.

For example: (a) Sources, e.g., planning and specification of paging systems, clinical and monitoring alarm systems; HVAC/ airflow equipment and other building mechanical engineering (MEP) systems; strategic placement of nursing stations and other dedicated areas where unamplified speech occurs; selection of audible monitoring alarm systems optimized for sound pressure levels; informational content, audibility, and their location. (b) Paths, e.g., design and configuration of the physical plant with attention to sound transmission, and specification of sound absorptive surface materials to limit sound mix-

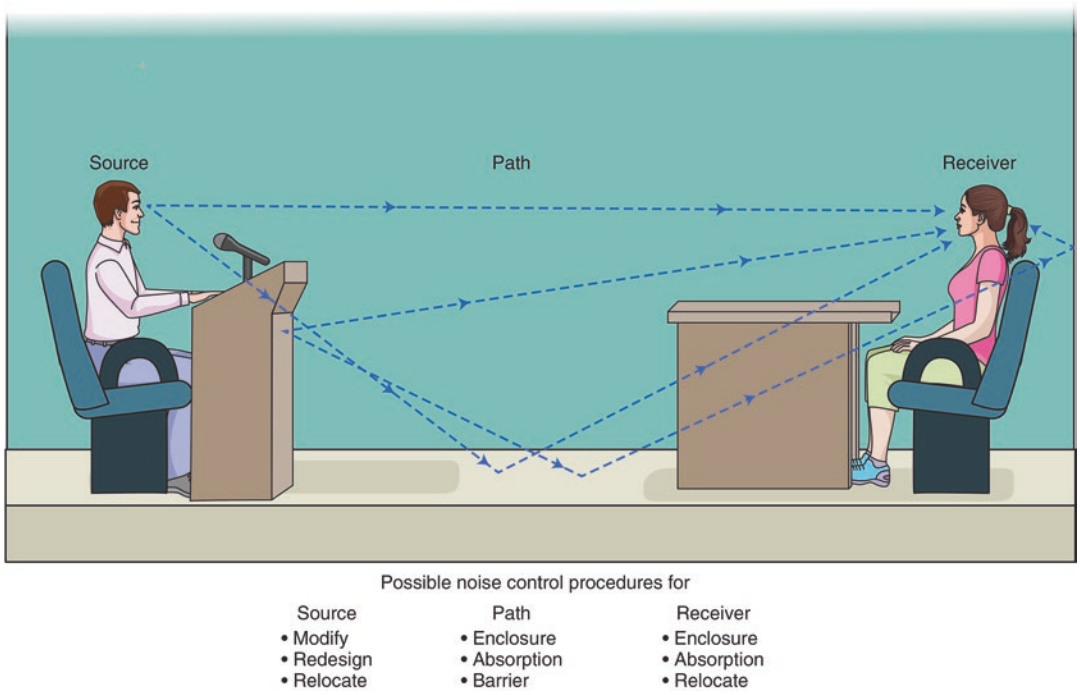

Fig. 17.1 Noise control procedures are applied to source, path, and receiver (Modified from [46])

ing and reverberation. (c) Receivers, e.g., modifying traffic flow and other behaviors through architectural and equipment layouts to ensure that caregivers and patients can hear and respond without being distracted, confused, and fatigued by high levels of ambient noise.

Numerous case studies demonstrate methods for reducing noise levels and improving signal-to-noise ratios through changes to programs, procedures, maintenance, and modifications to the physical environment [48]. Noise reduction measures found to be effective follow these same three parallel components: eliminating or reducing noise sources, for example, by replacing overhead paging with wireless communication devices carried by staff; insulating loud noise sources such as ice machines and pneumatic tubes, and conducting group conversations in an enclosed space; and modifying transmission by installing sound-absorbent surfaces such as high performance ceiling tiles and providing receiver protection such as in single-bed patient rooms [49].

The Role of Alarm Standards and Codes

There are three main standards relating to alarm signals as recognized by the U.S. Food and Drug Administration: (a) IEC/ISO 60601-1-8:2006 Ed.2: medical electrical equipment, part 1–8: general requirements for safety—collateral standard: general requirement, tests, and guidance for alarm systems in medical electrical equipment and medical electrical systems; (b) ANSI HE75: 2009, human factors engineering—design of medical devices; and (c) IEC62366, medical devices—application of usability engineering [50].

The current international standards for alarms, IEC 60601-1-8, stipulate that medical device audible alarms should be priority encoded and validated for efficacy. Yet, evidence shows that the melodic alarms described in the standard do not function in situ as intended [51]. Clinical urgency information when patients are in distress needs to be encoded using a human factors paradigm for alarm design via modulation of the

physical characteristics of sounds. New standards should be developed to bring consistency across devices and manufacturers [52].

There is little evidence, however, that the urgency-encoding standards proposed in IEC 60608-1-8 actually works in a complicated and noisy operating room environment where task loads and ambient noise can be significant [53]. An important point stressed in the IEC standard is that any new audible alarm be validated before implementation. However, the suggested melodies and the suggested method for urgency encoding espoused by the standard were never, themselves, validated in clinical real-world—let alone in simulated—clinical settings [54]. Furthermore, the standard does not offer a validation method [55].

Standards and guidelines relating to alarms and ambient noise levels in healthcare facilities can be found in the Guidelines for the Design and Construction of Health Care Facilities (2014) from the Facility Guidelines Institute (FGI) [56] and the Sound & Vibration Design Guidelines 2.0 [57]. These two documents are referenced in the Joint Commission report Planning, Design, and Construction of Health Care Facilities, 2nd Edition [58], and in the U.S. Green Building Council's new LEED Rating System for Health Care [59]. In addition, a new IEC standard is in draft: IEC 80001-2-x: application of risk management for IT networks incorporating medical devices offering guidance on the integration of alarms.

The Role of Medical Device Designers and Manufacturers

Medical devices in the operating room often suffer from fundamental flaws in their interface design and thus impair alarm usability. Manufacturers are required by the FDA to investigate deaths when hospitals report them as monitor related, but almost always attribute the patient deaths to human error, concluding that monitors worked correctly but staff misprogrammed them or didn't respond appropriately [60]. Most current medical device systems, for example, do not relay information in real time. In typical use, data acquired from medical devices goes to a queue that waits for a clinician to validate before it is pushed into the chart. Innovative data mining and ongoing trend analyses could better indicate patient deterioration and facilitate relevant clinical action before full 'rescue' efforts are initiated. This level of interoperable connectivity requires cooperation between vendors. Medical device vendors want to control the mechanisms and alerts associated with their devices to create end-to-end proprietary solutions. Without pressure from clinicians and purchasers, common business concerns will keep device and healthcare IT manufacturers from collaborating on solutions that could help mitigate persistent alarm problems. Healthcare providers can be better technology consumers by advocating for what they need from vendors. Providers should identify the gaps in current alarm notification systems and draft requirements for future purchases. Vendors, expectedly design equipment and interfaces with a "device-centric" perspective at the Point of Care (POC). Meaningful improvements in patient safety require that alarms be clinically significant and are integrated to the sociotechnical environment using a "patient-centric" approach [61].

Advocating for Change to Improve Alarm Management (Fig. 17.2)

Addressing alarm fatigue will require changes in how individuals and teams address noise measures. Any approach must be grounded in team theory, account for individual and team-level performance, processes and outcomes, adhere to standards for reliability and validity, and address barriers to measurement. A 2011 summit addressed alarm fatigue focusing on the pragmatic aspects of training staff and offered a number of recommendations for research in the real clinical setting where alarms must function to help teams deliver safe care [62].

Organizational Environment: The Role of Clinical Microsystems in Addressing Alarms

Noise and alarm management exist within the context of technology, providers, and patients, i.e., a system. A system is a set of interacting, interrelated, or independent elements that work together in a particular environment to perform the functions that are required to achieve a specific aim. A clinical microsystem is a group of clinicians and staff working together with a shared clinical purpose to provide care for a population of patients [63]. The clinical purpose and setting define the essential components of the microsystem, which include clinicians, patients, and support staff; information and alarm technology; and specific care processes and behaviors that are required to provide care. The best microsystems evolve over time, as they respond to the needs of their patients and providers, as well as to external pressures such as regulatory requirements. They often coexist with other microsystems within a larger (macro) organization, such as a hospital [64].

Guiding Principles in Alarm Management

In an April 2013 Sentinel Event Alert, the Joint Commission cited 98 alarm-related events over a three-and-a-half-year period, with 80 of those events resulting in deaths [65]. In June 2013, the Joint Commission announced the creation of a new National Patient Safety Goal (NPSG) focused on clinical alarm safety. This NPSG calls on each hospital to understand its own situation and to develop a systematic, coordinated approach to alarm deaths and permanent loss of function. Addressing clinical alarm hazards requires a comprehensive alarm management program involving stakeholders throughout the organization.

Best practice goals for hospital alarm management programs should include (1) minimizing the number of clinically insignificant or avoidable alarms so that the conditions that truly require attention can better be recognized, and (2) optimizing alarm notification and response protocols so that the patient receives the appropriate care at the time it is needed. Institutions can improve management of cardiac monitor

Fig. 17.2 Alarm management program. (Modified from ECRI [70]).

Table 17.3 Institutional alarm management strategy

• Establish a broad-based multidisciplinary alarm working group
• Understand the recurrent manufacturer alarm defaults
• Extract and evaluate their alarm data
• Observe staff response to alarms, looking for the barriers to timely response
• Identify with clinician stakeholders clinically insignificant alarms
• Remove audible notification for clinically insignificant alarms
• Choose an alarm setting that requires staff response for all clinically significant alarms
• Standardize alarm defaults across patient care units wherever possible
• Empower nursing staff to eliminate false alarms, appropriately adjusting alarm in real time after validation with second registered nurse

Table 17.4 Alarm management guiding principles

• The organizational complexity of healthcare must be recognized
• Patient-centered health services means that the patient's perspective and acoustic well-being must be central to all healthcare policy, planning, and procurement decision making
• Quality healthcare includes all aspects of service delivery: clinical and nonclinical
• Patient safety must be the foundation of acoustic decisions regarding alarm management
• Systems of care, and facilities, as well as individuals, affect the quality of healthcare
• Learning from error, rather than seeking someone to blame, must be the priority of health policy makers in order to improve safety and quality
• Openness and transparency are crucial to the development of trust between health facility procurement and healthcare professionals, patients and consumers, and the wider public

Table 17.5 Focus on alarm parameters

• Implement safety checks on alarm settings
• Revise default alarm parameters in each unit to actionable levels—recognize that settings may vary from one unit to another
• Implement revisions/changes incrementally
• Prioritize and differentiate between actionable alarm signals in each unit, e.g., visual vs. auditory (recognize that settings may not be the same from one unit to another)
• Define alarm condition types, e.g., false, true, nuisance, unactionable, etc., and assure that definitions are understood by unit staff
• Gather quantitative baseline data to evaluate alarm conditions
• Examine logs from the network that track alarm messages from devices in order to capture the quantitative data
• Observe alarm condition patterns and distinguish between alarm conditions
• Compare pre- and postdata to measure changes

alarms without requiring additional resources or technology (Table 17.3).

The environment has a significant impact on the ability of clinicians to build trusting, therapeutic relationships. The physical structure and design of healthcare buildings must support the model of care with appropriate physical, social, and symbolic environments. The design process for healthcare environments needs to be radically changed to address the needs of patients, providers, and the community at large. We are moving from a decade of highly structured top-down programs to local ownership and more transparent community partnerships. Engagement strategies need to include: (1) get clinicians 'moving and experimenting' with their own systems; (2) provide permission, space, and time for clinicians to find purpose and set their own direction in partnership with their patients and consumers; (3) direct attention through hyper transparent measuring, collating, and sharing of data about 'what is happening' at the service delivery level; and (4) facilitate respectful interaction between clinicians and managers (Table 17.4).

Creating an environment where a culture of patient safety can flourish is a daunting challenge [66]. Innovation will not happen if participants in the process are not invited or are unable to think outside the constraints of convention especially if they are unwilling to challenge the risk-averse nature which characterizes the cultural and intellectual development of so many of our professional and commercial institutions. Designing better methods to learn from adverse events that are caused or are part of a larger adverse event is key to changing clinicians' attitudes towards alarm-related events [67]. Designing new training programs and assessing learners in a more holistic and meaningful way will require innovative training and engagement approaches (see Table 17.5).

Table 17.6 Training recommendations

• Undertake risk analysis of patient populations within acute care facilities to develop standards for monitor assignment and continuation
• Examine indicators of patient deterioration such as respiration rate, pulse rate/heart rate, systolic blood pressure, pulse oximetry, to determine which indicators should be monitored
• Design simulation scenarios from reported harm or near misses with trigger events that link alarm fatigue and teamwork skills to training objectives and specific competencies
• Design a parallel set of scenarios that can be used to evaluate the effectiveness of training these specific competencies
• Develop and apply measures of success in alarm management
• Embed training in alarm management into multidisciplinary teams so members train in the context in which they will work

Asking the right questions while focusing on the correct parameters that mean the most to providers can go a long way to gain trust of providers (Table 17.6) [62].

Conclusions

Hospital noise routinely exceeds international, WHO noise acceptable standards and is more than just an annoyance. This failure to provide patients with quiet rooms due to alarms and other ambient noise affects clinical outcomes through several mechanisms, including sleep deprivation, cardiovascular derangements (increased heart rate and blood pressure), poor wound healing, higher incidence of readmissions, patient falls, pain, stress, and dissatisfaction [65]. Moreover, poor acoustic clinical environments are associated with excessive cognitive load on staff, and interference with speech and communication among healthcare professionals, both of which can increase risk of medical errors and patient harm [68]. Improving acoustic environments of hospitalized patients has been shown to decrease rehospitalization rates, improve sympathetic arousal, and raise patient satisfaction as compared with conventional hospital environments [42].

If, however, alarm function is considered to be that of maintaining situational awareness, designers need to engineer monitor devices able to do some or all of the following: distinguish artifact from real state changes, determine the importance of state changes within context, convey alarm source, and allow prioritization when operating attention is directed elsewhere (e.g., during line placement) or when multiple alarms sound. Development of more advanced device algorithms is needed to balance the sensitivity and specificity in triggering alarm signals, to block artifacts, and to produce clinically relevant alarms. Real-time trend analyses must be conveyed so care can be delivered before full patient rescue is required. Hospitals need a system-wide alarm policy and protocols that define the alarm management strategy for alarmed medical equipment, and delineate how caregivers/nurses respond to alarm conditions and signals. These conditions produce an "acoustic feedback loop" in which noise inevitably and rapidly escalates to intolerable levels and interfere with behavior. It is imperative to use a human factors-based approach based around the hospital's culture and engage architects, designers, acoustical engineers, facility engineering, staff, and clinicians to address alarm fatigue and its implications on the physical built environment [69]. Involving patients in the redesign of hospital acoustic environments may also improve patient experiences and satisfaction with their hospital care. There is a compelling role for industry cooperation that will facilitate device linkages to limit alarm redundancy, standardize, and scale alarm signals to convey urgency, develop alternative modalities and sensory channels, and enhance options for central oversight.

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