Technologic Distractions (Part 1): Summary of Approaches to Manage Alert Quantity With Intent to Reduce Alert Fatigue and Suggestions for Alert Fatigue Metrics

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Supported, in part, by the Gordon and Betty Foundation, as a grant to the Society of Critical Care Medicine, Mount Prospect, IL.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website (http://journals.lww.com/ccmjournal).

The authors disclosed that funding was provided by the Gordon and Betty Foundation, as a grant to the Society of Critical Care Medicine. Dr. O'Connor disclosed off-label product use of ignoring or bypassing alarms and alerts built into sensors, monitors, and computer decision support systems. Ms. McLean received funding from Edwards Lifesciences and the American Association of Critical Care Nurses. Dr. Winters received funding from performing medical legal work for a variety of law firms, UpToDate (royalties), and he disclosed that he is on the board of a start-up called Intellix Checklists, Inc.

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DOI: 10.1097/CCM.0000000000002580

Objective: To provide ICU clinicians with evidence-based guidance on tested interventions that reduce or prevent alert fatigue within clinical decision support systems.

Design: Systematic review of PubMed, Embase, SCOPUS, and CINAHL for relevant literature from 1966 to February 2017.

Patients: Focus on critically ill patients and included evaluations in other patient care settings, as well.

Interventions: Identified interventions designed to reduce or prevent alert fatigue within clinical decision support systems.

Measurements and Main Results: Study selection was based on one primary key question to identify effective interventions that attempted to reduce alert fatigue and three secondary key questions that covered the negative effects of alert fatigue, potential unintended consequences of efforts to reduce alert fatigue, and ideal alert quantity. Data were abstracted by two reviewers independently using a standardized abstraction tool. Surveys, meeting abstracts, "gray" literature, studies not available in English, and studies with non-original data were excluded. For the primary key question, articles were excluded if they did not provide a comparator as key question 1 was designed as a problem, intervention, comparison, and outcome question. We anticipated that reduction in alert fatigue, including the concept of desensitization may not be directly measured and thus considered interventions that reduced alert quantity as a surrogate marker for alert fatigue. Twenty-six articles met the inclusion criteria.

Conclusion: Approaches for managing alert fatigue in the ICU are provided as a result of reviewing tested interventions that reduced alert quantity with the anticipated effect of reducing fatigue. Suggested alert management strategies include prioritizing alerts, developing sophisticated alerts, customizing commercially available

alerts, and including end user opinion in alert selection. Alert fatigue itself is studied less frequently, as an outcome, and there is a need for more precise evaluation. Standardized metrics for alert fatigue is needed to advance the field. Suggestions for standardized metrics are provided in this document. (*Crit Care Med* 2017; XX:00–00)
Key Words: alert burden; alert fatigue; clinical decision support systems; critical care; electronic health records; intensive care unit

The Center for Medicare and Medicaid Services was authorized by Health Information Technology for Economic and Clinical Health Act to provide incentives for hospitals to encourage the meaningful use of electronic health records (EHRs) to improve care delivery. This is beyond simple adoption of EHRs and includes application with the goal of advancing health-care processes and outcomes (1). Most hospitals (97.5%) responding to a national survey indicate partial or complete implementation of an EHR and state that they use computerized prescriber order entry and clinical decision support systems (CDSS) at 84% and 65%, respectively (2, 3). Terminology used in this review is described in **Table 1** (4–13). Achieving meaningful use of the EHR includes using CDSS as it is a core measure (6).

CDSS are commonly used for preventing medication errors and is gaining use as an electronic syndromic surveillance system for events such as sepsis and acute kidney injury. It is also used to assist with guideline adherence. These applications for CDSS are frequent in the ICU, resulting in an unprecedented number of alerts delivered to clinicians. One study reports that clinicians review 123 alerts to prevent one adverse event (14). Although CDSS improves patient outcomes (15), the quantity of alerts creates risk of alert fatigue (14).

Alert fatigue results when a clinician is exposed to an excessive number of alerts becoming desensitized, thus ignoring alerts leading to possibly overlooking a clinically relevant alert (Table 1). On the other hand, alert override is often appropriate because of poor alert design, lack of clinical relevance, or oversensitive alerts. Still, alert override has the possibility of resultant adverse events (16, 17).

We performed a systematic review to provide clinicians with evidence-based guidance on tested interventions that reduce alert fatigue within CDSS. We anticipated alert fatigue including the concept of desensitization could not be directly measured and thus considered interventions that reduced alert quantity as a surrogate. One primary key question (KQ) was evaluated to identify effective interventions that reduce alert fatigue and three secondary KQs covered negative effects of alert fatigue, potential unintended consequences of reducing alert quantity, and ideal alert quantity.

MATERIALS AND METHODS

A systematic literature review was conducted in accordance with the Meta-analysis of Observational Studies in Epidemiology guidelines (18) covering four KQs focused.

TABLE 1. Definitions for Terms Relating to Alerts

Term	Definition
Signal or trigger (4, 5)	Clues (drugs, laboratory results, drugs) suggesting the presence of an adverse event. Signals are used to build rules within a clinical decision support system that generate alerts when specific criteria are met. Use of triggers is recommended by the Institute for Healthcare Improvement to identify adverse drug events. Triggers can be used manually or automated.
Alert (6, 7)	Automated application of triggers can be used to generate alerts. An alert is a warning or informational "pop-up" generated after the criteria for the rules associated with the signal have been met within clinical decision support.
Alert fatigue (8)	"Describes how clinicians become desensitized to safety alerts and as a result ignore or fail to respond appropriately to such warnings."
Alert override	Occurs when the clinician dismisses or bypasses the alert. This may be an appropriate or inappropriate action.
Alert value	Alert that appropriately flags the attention of the clinician in a timely manner allowing the opportunity for intervention in patient care (i.e., clinically significant).
Electronic health record (9)	"Electronic version of a patient's medical history maintained by the provider over time."
Computerized Prescriber Order Entry (10)	"Refers to any system in which clinicians directly place orders electronically, with the orders transmitted directly to the recipient."
Clinical decision support systems (11, 12)	"Any system designed to improve clinical decision making related to diagnostic or therapeutic processes of care. Clinical decision support systems link patient data with an electronic knowledge base to improve decision-making."
Electronic syndromic surveillance (13)	A type of clinical decision support systems is electronic syndromic surveillance as it "aids in clinical decision-making through the systematic collection, analysis and interpretation of ongoing clinical data and dissemination of results."

Primary KQ:

1. What interventions were attempted to improve alert quantity as a marker of fatigue compared with a control in any setting?

Secondary KQs:

2. What are the negative effects of alert fatigue?
3. What are the balancing outcomes or negative consequences of reducing the number of alerts?
4. What is the ideal alert quantity to avoid fatigue?

We searched PubMed, Embase, SCOPUS, and CINAHL for relevant literature from 1966 to February 1, 2017 (**supplemental methods**, Supplemental Digital Content 7, http://links.lww.com/CCM/C727; and **Supplemental Digital Content Alarm—Alert Search String**, Supplemental Digital Content 1, http://links.lww.com/CCM/C721). We excluded studies not in English and with nonoriginal data (reviews, editorials, and commentaries). We excluded surveys, meeting abstracts due to lack of detail, and "gray" literature that were not peer reviewed. Identifying effective interventions to reduce alert fatigue in ICU environments was our focus; however, alert fatigue is a problem extending beyond the ICU, and thus we included articles regardless of environment (i.e., inpatient and outpatient). We preformed the snowball method for identifying additional articles by manually searching references of selected articles.

For KQ 1, articles were excluded if they did not provide a comparator as KQ 1 was designed as a problem, intervention comparison, outcome (PICO) question per Grading of Recommendations, Assessment, Development, and Evaluations criteria (19, 20). For KQ 1, we did not specifically require "alert fatigue" was measured but instead settled on reduction of alert quantity including improvement in alert performance to reduce quantity. We felt alert quantity reduction could be loosely translated into reducing alert fatigue. We felt, in addition to alert quantity, the other two components of alert fatigue were inappropriate overrides and desensitization, as alert fatigue is ignoring or failing to respond appropriately (**Fig. 1**) (8). Data on both these components were abstracted for discussion. Finally, we abstracted data on alert value as measured by number of accepted alerts, decrease in override rates, or judged as clinically significant.

RESULTS

Supplemental search strategy (Supplemental Digital Content 2, http://links.lww.com/CCM/C722) illustrates the results providing a total of 26 articles for inclusion. Studies identified supporting each KQ and quality of evidence scores is provided in the tables in **Appendix KQ 1** (Supplemental Digital Content 3, http://links.lww.com/CCM/C723), **Appendix KQ 2** (Supplemental Digital Content 4, http://links.lww.com/CCM/C724), and **Appendix KQ 3** (Supplemental Digital Content 5, http://links.lww.com/CCM/C725). A table is not provided for supplemental digital content KQ 4 because no studies met inclusion criteria. KQ 1 is discussed below and the other KQs are summarized in **Table 2** and discussed in detail in the **supplemental data KQ 2**, **KQ 3**, and **KQ 4** (Supplemental Digital Content 6, http://links.lww.com/CCM/C726).

KQ 1. WHAT INTERVENTIONS WERE ATTEMPTED TO IMPROVE ALERT QUANTITY AS A MARKER OF FATIGUE COMPARED WITH A CONTROL IN ANY SETTING?

Nineteen studies answered this PICO question (21–39). All studies evaluated reducing alert quantity with one considering inappropriate overrides (33) and zero measuring desensitization. Metrics for alert value were evaluated in nine studies (21, 23, 24, 28–32, 37).

Modifying Rules for Drug Interaction and Allergy Alerts

A core measure for meaningful use of drug interaction CDSS exists in the Center for Medicare and Medicaid Services' guidelines (40, 41). Still, drug interaction alerts are often overridden

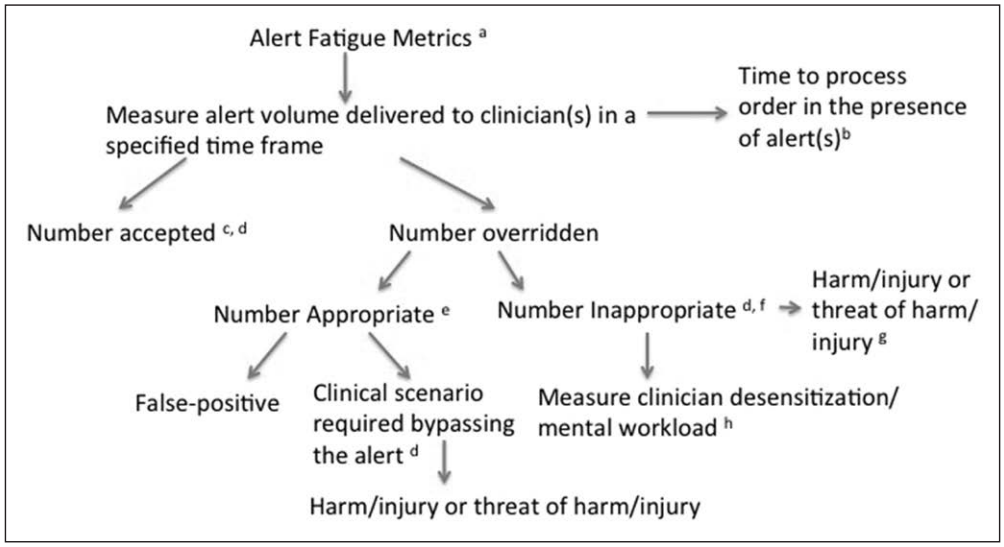

Figure 1. Alert fatigue metrics. [a]Alert fatigue = proportion of inappropriate overrides to total alert quantity in the presence of desensitization or high level of mental workload. [b]Delayed processing time is a negative consequence of alert volume; a correlation between alert volume and processing time is a valuable information; it may also be useful to evaluate this for appropriate and inappropriate overrides, separately. [c]Accepted = change in therapy or additional monitoring. [d]Alert value = appropriate alerts delivered in a timely manner including alerts that are accepted "plus" alerts with appropriate overrides warranted because of the clinical scenario plus alerts with overrides that were inappropriate. [e]Alert quantity and appropriate overrides provide information about opportunities to improve alert performance. [f]Inappropriate = true positive alert overlooked and not warranted by clinical scenario. [g]Harm or threat of harm is a negative consequence of alert fatigue and is an important outcome to measure. [h]Deb and Claudio (48).

TABLE 2. Summary of Findings for Key Question 2, 3, and 4

Key Question	Summary of Findings[a]
KQ 2: What are the negative effects of alert fatigue?	Frustration and annoyance
	Decline in memory recall about alert
	Inappropriate override response
	Delay in processing orders
KQ 3: What are the balancing outcomes or negative impact/consequences of reducing the number of alerts?	Reducing alert quantity may "not" have an impact on clinician override rates/acceptability
	Reducing alert quantity compromises the sensitivity of alert system possibly leading to missed opportunities to avoid adverse patient outcomes
KQ 4: What is the ideal alert quantity to avoid alert fatigue?	No data on ideal alert quantity were identified

KQ = key question.

[a]Details of findings discussed in Supplemental Digital Material key question (KQ) 2 (http://links.lww.com/CCM/C723), KQ 3 (http://links.lww.com/CCM/C724), and KQ 4 (http://links.lww.com/CCM/C725).

and substantial contributors to alert fatigue. A hypothetical pre- and poststudy design was used to determine the effects of the new alerting system that tailored alert generation to a streamlined list based on expert opinion of interacting drugs causing QT-prolongation (36). The preintervention alerting system had a sensitivity of 47% and a positive predictive value (PPV) of 31% in a subset of 49 patients. The new alerting system resulted in a 53% reduction in alerts and PPV of 30% for the same patient cohort. So, this approach reduced alert quantity but did not identify patients at higher risk for adverse outcomes.

Streamlining the list of potentially interacting drugs to reduce alert quantity generation based on expert opinion is one approach; others have applied a systematic approach with severity rankings and irrelevant alerts. An absolute reduction in drug interaction alerts was approximately 9–35% depending on alert type and if a clinician response was required to proceed with processing the drug order (22, 34, 35, 37). In contrast, the same concept of modifying alert severity resulted in an alert increase from 6.5 to 10.4 alerts/1,000 prescriptions in a pre- and postintervention assessment, respectively (28). Despite alert quantity increase, modifications were deemed successful by the authors because physician acceptance increased 50% in the postintervention group. A better interpretation would be alert value improved but not alert quantity reduction. Overall, manipulating severity of drug interactions had mixed results with significant reduction to no reduction in alert quantity.

Alert quantity associated with drug interaction CDSS was reduced by deactivating irrelevant alerts (32). Number of alerts significantly decreased by 33.6 and 4.6 alerts per 100 orders for pharmacists and physicians after modification, respectively. Interestingly, the override rate decreased for pharmacists presumably due to less alert fatigue. A similar approach of reducing irrelevant (i.e., inactive ingredients) drug allergy alerts was taken and resulted in a dramatic 67% reduction in alerts, suggesting that strategic selection of alerts based on clinical relevance can be beneficial in reducing quantity (39).

Seven of the eight studies that modified rules for alert generation in drug interaction CDSS resulted in a reduction in alert quantity with one demonstrating a negative outcome of missing potential adverse events. Still these efforts may only be the first step of a multimodal plan for alert reduction since an absolute change of greater than 9% is likely necessary to impact alert fatigue (35).

Learning From Alert Overrides

Similar to the idea of removing irrelevant alerts pertaining to drug interactions, this concept could be applied to other alerts. A retrospective analysis of data on alert generation and clinician override responses was conducted (38). The goal was to develop an algorithm to automatically filter previously overridden alerts (i.e., remove irrelevant alerts) based on learned clinician practices by predicting future overrides with cognitive and statistical methods. Application of the algorithm resulted in a 27.4% reduction in alerts generated, but of these 6.3% would not have been overridden by the clinician.

Making Sophisticated Rules for Alert Generation

Increasing sophistication of alerts can improve specificity, thus removing irrelevant alerts. Basic CDSS was compared with CDSS with more sophisticated alerts that included an assessment of the patient's risk for an adverse drug event by evaluating laboratory data, patient characteristics, and medications (21). Advanced CDSS resulted in an average of 64.8 compared with 74.0 alerts per day with the basic CDSS for the same patients. This comparison was repeated prospectively and found more alerts with the advanced system.

Still other studies have shown a benefit to developing sophisticated alerts with an advanced system having a higher number of relevant alerts and a higher PPV, although still low at 17% (23). Each modification of a drug-induced thrombocytopenia alert to make it more sophisticated resulted in equivalent or slightly increased PPV for an ADE (26). Four versions of a drug-induced acute kidney injury alert that increased in sophistication decreased in alert quantity by up to 80% (34).

Making sophisticated alerts has potential to decrease alert quantity and improve alert value. Three of the four studies discussed were not as impactful as expected, but there was improvement and marked progress was observed in the acute kidney injury study (34). We are just beginning to understand alert performance optimization to avoid false positives. It will likely require even more sophisticated rules for alert generation (42).

Using Alerts for Rare Events

Selecting atypical medication orders as a focus for alerts can increase specificity and reduce alert quantity compared with conventional drug dosing alerts. Woods et al (33) conducted a study of atypical medication order alerts, defined as medication orders that never or rarely appeared in historical order data, for five medications. There were 68 alerts generated for 18,019 orders, with a 0.4% alert to order rate compared with much higher rates reported in other studies of 5–36%. Despite the lower alert quantity, many of the overrides still had potential for harm. Alert quantity can be controlled with a focus on rare events but does present risks.

Physicians' Preference for Alert Selection

An on-demand system that permitted physicians to select when they wanted to receive alerts, thus reducing alert quantity, was compared with a computer-generated system and the alert quantity was 0.03 and 0.1 alerts per patient, respectively (31). Less prescribing problems were viewed by physicians in the on-demand group. Overall, allowing physician customization of alerts may diminish quantity but compromise the intended benefit of medication error and ADE reduction.

Customizing Commercial Systems

Often commercially available CDSS are designed to be sensitive and not specific, resulting in excessive alert quantity. A commercially available system was evaluated in a pre- and postintervention-controlled trial design with the intervention being customization of available alerts to increase specificity (29). Alert rate was decreased to less than 1% for orders screened in the postintervention phase. In the postintervention phase, the pharmacist contacted physicians for 20.6% of alerts and physicians changed doses for 7.9%, suggesting there is still an opportunity to develop more clinically significant alerts. Customization of a commercially available CDSS with the intent of reducing alert fatigue is common (27, 29, 30).

Selecting Commercially Available Systems

The most effective CDSS for an institution may be a healthy discussion in advance of implementation. Commercially available systems have different rules and different criteria for alerting. A prospective evaluation of three CDSS occurred for 100 patients resulting in 53, 362, and 328 alerts for Pharmavista, DrugReax, and TheraOpt, respectively (24). Thirty-three alerts were judged to be clinically significant, and the PPVs ranged from 5.7% to 8.0%. So, overall none of the systems performed well. Also, the system with the least alerts generated was the least sensitive at detecting clinically relevant alerts. Another study compared alert quantity for two drug interactions CDSS (25), and both generated a substantial number of alerts although more with MediQ (4.3 alerts/patient) than ID PHARMA (3.3

TABLE 3. Interventions for Application to Reduce Alert Fatigue

Intervention	Reduce Alert Burden[a]
Interventions Tested in a Clinical Environment	
Prioritizing alerts based on severity and clinical relevance (22, 28, 32, 34–37, 39)	+
Learning from previously overridden alerts to avoid future alerting (38)	+
Making more sophisticated alerts by incorporating biochemistry data and patient characteristics (21, 23, 26, 34)	+/–
Focusing on atypical or rare prescribing events (33)	+
End user opinion in use of alerts (31)	+
Customizing commercially available systems (27, 29, 30)	+
Appropriate selection of a commercially available system (24, 25)	+
Proposed interventions to be evaluated	
Incorporating alerts outside of workflow to be adjudicated before contacting the prescribing clinician	
Designing alerts to be highly specific to an event and find a balance with sensitivity	
Design alerts for the patient care setting (i.e., ICU) instead of an institution-wide approach	
Use machine learning techniques to advance the quality of the alerts and adjust to current practices (42)	
Adjust alert thresholds to meet more serious criteria (i.e., drug-induced hyperkalemia set to 6.0 mEq/L instead of 5.5 mEq/L)[b]	
Consider the method of delivery: interruptive for severe alerts and passive for less severe alerts	
Use machine learning to individualize alert delivery based on physician response characteristics (i.e., time of day; alert quantity per day; alert severity)	
End-user acceptance in the design of alert format and content specific to the ICU	

[a]Based on evidence provided in the systematic review.

[b]This is a trade-off between preventing an event and detecting an event.

+ Represents an overall positive outcomes for the studies presented in these subcategories for key question (KQ) 1, irrespective of number of studies or quality of the study. +/– Represents conflicting outcomes for the studies presented in these subcategories for KQ 1.

alerts/patient). These studies do not specify interventions to manage alert fatigue but commercially available CDSS have inherent differences contributing to alert fatigue.

DISCUSSION

This review focused on identifying interventions with an impact on alert fatigue (summarized in **Table 3**); however, it was necessary, a priori, to use reduction in alert quantity and improving performance characteristics (i.e., PPV) as a surrogate for alert fatigue because of challenges in measuring desensitization. Most systems altering drug interaction severity, reducing clinically insignificant alerts or customizing commercially available CDSS, did result in alert quantity reduction but with some negative consequences (Table 2). It is probably necessary to bundle interventions with a multimodal approach to overcome alert fatigue to obtain the maximum benefit (43). Ideally, institutions should request, review, and evaluate data on the performance characteristics before purchasing a CDSS for organizational use. Advancing CDSS to be integrated with other information systems such as laboratory data, physiologic data, medication administration data, and patient characteristics have the potential to make sophisticated alerts. However, alert fatigue reduction was inconsistently observed in the studies evaluating the advanced CDSS concept (21, 23, 26). A more detailed analysis of possible reasons for unequivocal findings is needed. Advanced alerting systems did enhance alert value with more interventions (21).

Most suggestions provided in Table 3 were derived from studies outside the ICU, mostly for the entire hospital. Alert fatigue is a problem extending beyond the walls of an ICU, so gleaning information for effective strategies from a variety of environments was deemed appropriate but there is need to test these approaches for impact in the ICU. Also, many studies included in this review evaluated alerts for medication-related events, although, our search was not limited to medication-related CDSS. The use of electronic syndromic surveillance systems for the early recognition of specific conditions such as sepsis and acute kidney injury are increasing both within and outside of the ICU. Unfortunately, we found no studies evaluating such systems in terms of alert fatigue. It is important to manage alert fatigue because clinically significant alerts can be missed, leading to negative patient consequences (32, 44, 45). Also, alert fatigue can negatively affect the end user's memory recall and cause frustration that leads to job dissatisfaction (46, 47).

Our reliance on a surrogate marker for alert fatigue required us to note the need for a standardized metric to advance the field. We propose alert fatigue is measured by the proportion between alert quantity and the number of inappropriate overrides, in the presence of desensitization or high level of mental workload (Fig. 1). Deb and Claudio (48) offer a method to measure mental workload using two tools: Subjective Workload

Assessment Technique and National Aeronautics and Space Administration-Task Load Index. Although the ideal measurement for desensitization requires further investigation, the approach by Deb and Claudio (48) is a reasonable beginning. Alert quantity requires consideration in the context of appropriate and inappropriate overrides. Knowing the appropriate overrides will aid in finding interventions to reduce quantity. We introduce the concept of alert value. An alert is valuable if it appropriately flags the clinician's attention in a timely manner allowing for intervention. Number of accepted alerts does contribute to alert quantity; however, improving alert acceptance enhances alert value but does not necessarily reduce fatigue without reduction in the total quantity of alerts. An important consideration for institutions is an active quality improvement program that prevents and responds to alert fatigue using appropriate data for meaningful use of CDSS (**Table 4**).

LIMITATIONS

Our search criteria were inclusive; however, there is the possibility that relevant articles were not identified. Quality of the evidence scores provided in the supplemental digital content KQ tables (Appendix KQ 1 [Supplemental Digital Content 3, http://links.lww.com/CCM/C723], Appendix KQ 2 [Supplemental Digital Content 4, http://links.lww.com/CCM/C724], and Appendix KQ 3 [Supplemental Digital Content 5, http://links.lww.com/CCM/C725]) was completed by two reviewers and consensus was not sought among all authors. Our suggestions for interventions to aid in alert fatigue management are based mostly on hospital data. Literature encompassing building effective alerts considering human factors is expansive and beyond the scope of this review.

CONCLUSIONS

Approaches for managing alert fatigue are provided after reviewing tested interventions that reduced alert quantity with the anticipated effect of reducing fatigue. Alert fatigue, as an outcome, is studied less frequently and there is a need for more precise evaluation. A standard metric for evaluating alert fatigue including determining the proportion of inappropriate overrides relative to alert quantity in the presence of

TABLE 4. Components of a Quality Improvement Program

1) Design alerts for prevention and detection of events with clear delineation of the alert goals
2) Determine the priority and clinical significance (i.e., strength of evidence) of alerts before implementation with organization support and alignment
3) Determine who should respond to the alert, the mode of delivery, and a reasonable response time
4) Evaluate the performance characteristics of the alerts after implementation
5) Be ready to revise the alerts based on the performance characteristics
6) Be able to change alerts based on changes in practice
7) Education and implementation plans to support alert introduction including clear advice on expected actions

desensitization is proposed. Standardization will aid in prioritizing and implementing alerts with meaningful use. It is likely that reducing alert fatigue will require a multimodal approach to implementing effective interventions. A quality improvement program focused on appropriate alert implementation and management is a key component to successful alert fatigue reduction.

ACKNOWLEDGMENTS

We acknowledge Mr. Allen Zhang from the Johns Hopkins Evidence Based Practice Center for his assistance with the literature search and managing Distiller (Evidence Partners, Ottawa, ON, Canada). We also appreciate the efforts of Dr. Vishakha Kumar as the staff partner with the Society of Critical Care Medicine in managing the alert and alarm fatigue taskforce. We are thankful to Society of Critical Care Medicine, Mount Prospect, IL, for the development and support of alert and alarm fatigue taskforce.

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