Challenges of Customizing ECG Alarm Settings in Intensive Care Units: A Mixed Methods Study

Introduction

Physiologic monitor alarms are meant to enhance patient safety by alerting clinicians to changes in patient conditions and technical problems. However, research indicates fewer than 15% of monitor alarms may be accurate or immediately relevant to patient care (Bonafide et al., 2015; Bonafide et al., 2017; Drew et al., 2014; Paine et al., 2016). Excessive inaccurate and irrelevant alarms lead to alarm fatigue, a condition in which nurses become desensitized and lose trust in alarms to signal important events. This results in delayed or absent response to alarms, missed true events, and compromised patient safety (Bliss, Gilson, & Deaton, 1995; Sendelbach & Funk, 2013; The Joint Commission, 2013).

One mechanism for reducing the number of alarms and improving their relevance to patient care is customization of monitor settings to reflect individual patient conditions. Customization is distinct from changing default alarm configurations for an entire unit or patient population, and is also referred to as adjusting, tailoring, or individualizing alarms. Customizing alarms requires the nurse to determine safe alarm settings for each patient, so that irrelevant alarms are minimized, but clinically significant events still trigger an alarm. If an alarm is inappropriately customized, a true and clinically relevant alarm could be suppressed. Nurses' clinical reasoning about how to customize alarm parameter settings likely follows the same trajectory as other clinical reasoning processes, influenced not only by patient data, but also by contextual factors, such as political and social context of the unit, workflow factors, and nurses' social and moral judgments about patients (Tanner, 2006).

Encouraging nurses to customize alarms has been part of quality improvement initiatives, yet research on alarm customization is limited (Christensen, Dodds, Sauer, & Watts, 2014; Fidler et al., 2017; Graham & Cvach, 2010; Sendelbach, Wahl, Anthony, & Shotts, 2015; Turmell, Coke, Catinella, Hosford, & Majeski, 2017). The Joint Commission (2016) has called for hospitals to implement alarm customization policies; however, we have limited understanding of how and when nurses customize alarms, and what barriers to practice exist. The purpose of this study was to generate an understanding of ICU nurses' approach to customization of physiologic monitor electrocardiography (ECG) alarms, by describing their customization practices and exploring their clinical reasoning and judgment about the process.

Methods

Design

We used a convergent parallel mixed methods design, in which we collected quantitative and qualitative data as two independent study strands, and integrated data after separate analyses were complete (Curry & Nunez-Smith, 2014; Fetters, 2013). We used a descriptive design for the quantitative strand examining the types and frequency of ECG alarms customized, and a qualitative interpretive descriptive approach (Thorne, 2016) to explore nurses' clinical reasoning and judgment in customization. Detailed presentation of the qualitative methods and findings are described elsewhere (Ruppel et al., in progress). For this study, we defined ECG alarm customization practices as any changes made to ECG alarm parameters on the physiologic monitor that are different from the default settings, including widening or narrowing alarm limits, or deactivating or activating alarms.

Setting

We conducted the study in three adult ICUs in a single academic medical center in the northeastern United States. The ICUs have a total of approximately 283 nurses. The three units have different patient populations (medical, cardiac, and surgical) and varying alarm reduction strategies in place. An institution-wide policy allows nurses to customize alarms based on patient condition. All three units use Philips IntelliVue monitors; two units use the Classic system and one uses PIICiX. Approval for this study was obtained from the affiliated Institutional Review Board.

Sample

Quantitative. To obtain data on the types and frequencies of alarms customized, we sampled patients' physiologic monitors from day and night shifts in the three ICUs weekly from April to June 2017. We included all physiologic monitors in active use on patients at the times of data collection. Monitors were excluded if alarm settings for that patient had already been reviewed at a previous visit. Ultimately, we collected alarm customization data from physiologic monitors for 298 unique patients, 147 in the 56-bed medical ICU, 71 in the 24-bed cardiac ICU, and 80 in the 14-bed surgical ICU. We obtained data from 104 patients' monitors during night shift and 194 during day shift, at least one hour into the start of the shift.

Qualitative. During the same period, we recruited nurses from the three ICUs for interviews on customization clinical reasoning. All permanent staff nurses from these units were eligible to participate. We recruited participants during change of shift huddles, by posting fliers on the units, and through unit managers. We used purposive sampling to obtain maximal variation by years of ICU experience, level of nursing

expertise, and shift worked. Recruitment continued until we reached data redundancy on each unit and fulfilled our sampling goals, resulting in a sample of 27 nurses. Nurses provided written informed consent before participation.

Data Collection

Quantitative. To obtain the quantitative customization data, one author (HR) collected data by comparing the patients' physiologic monitor settings for ECG alarms at the time of data collection to the default alarm settings for the unit. From the central station, the data collector recorded the number and types of ECG alarms customized by activating or deactivating alarms, or changing alarm limits, as well as the amount the limits were changed from the default settings. Table 1 displays ECG alarm types included in this study and default alarm settings for each unit. One author (HR) re-checked data entry on 10% of the forms, and, after scanning the forms into Microsoft Access®, manually confirmed all data against the original forms. The hospital data analytics team provided demographic data for patients whose physiologic monitors were included in the study. We assigned each patient an identification number to maintain anonymity.

Qualitative. One author (HR) conducted semi-structured telephone interviews with the nurses recruited from the three ICUs. We used Tanner's (2006) model of clinical judgment to develop interview questions to elicit factors related to nurses' clinical reasoning (e.g., How would you describe the culture around alarm management on your unit? What do you see as the purpose of customizing alarms? How do you determine by how much to change an alarm limit? Tell me about a time you had a negative experience as a result of customizing alarms, or alarms in general.) We collected

demographic data from the nurse participants and thanked them for their time with a $30 gift card.

Data Analysis

Quantitative. Alarm customization data and patient demographic data were analyzed in SAS 9.4 (SAS Institute Inc., Cary, NC), using univariate analyses. We calculated customization frequency for each type of alarm and the changes in alarm limits from the default setting. We examined the data within and across the three ICUs.

Qualitative. We analyzed nurse demographic data using SAS 9.4. We analyzed interview data concurrently with data collection. Interview length ranged from 22 to 62 minutes. A professional transcriptionist transcribed the interviews, and one author (HR) checked transcripts against the original recording to ensure accuracy. We de-identified the data for confidentiality purposes. We used thematic analysis (Braun & Clarke, 2014) to analyze the interview data. We employed Atlas.ti version 7 (Berlin, Germany) for coding and to maintain an audit trail of activities and data analysis decisions, as well as theoretical, methodological, personal, and analytic memos.

Integration. Once quantitative and qualitative data analyses were complete, we merged the findings, using side-by-side comparison (Curry & Nunez-Smith, 2014). We examined how the clinical reasoning process (qualitative) reflected the customization practices (quantitative). We also explored convergent and divergent data, by comparing frequency of alarms customized from the quantitative data with nurses' discussion of types of alarms they most frequently customized. The nurses who customized the alarms could not be identified in the quantitative data, so the nurses' interview data could not be compared directly with their own specific customization practices.

Results

Quantitative

Table 2 presents the demographic data for the patients whose physiologic monitors we reviewed. The mean age of patients was 62.8 ± 17.1 years, 60.8% were male, 72.3% white or Caucasian, and the median length of stay in the ICU was 142 hours (5.9 days) (IQR 60-278 hours). Alarm customization practices identified in the quantitative data are presented in Table 3. Monitors had a mean of 1.6 (± 2.3) ECG alarms customized (range 0-14; median 1, IQR 0-2). Of the 298 monitors included in the study, 58.7% (n=175) had one or more alarm(s) customized, either by changing a limit or by activating or deactivating an alarm; 49.0% (n=146) had at least one alarm limit customized and 32.9% (n=98) had at least one alarm activated or deactivated from the default setting.

Qualitative

Demographic data for the nurses who participated in the interviews are reported in Table 4. The 27 participants were primarily female (92.6%), with a bachelor's degree in nursing (92.6%), and had worked in an ICU for a mean of 10.5 ± 9.5 years (range 0.5-28 years).

In the thematic analysis, we found that alarm customization involved complex clinical judgement, with many factors influencing the clinical reasoning process. Both the *unit alarm culture* and *nurse attributes* (e.g., education, knowledge, experience, and "style") influenced the ways in which nurses engage in clinical reasoning and judgment about customization. For example, nurses with education on and knowledge of the detrimental effect of alarm fatigue and the importance of customization described

customization as important. Nurses with less experience in the ICU were typically less confident customizing alarms. Nurses who had had prior negative experiences related to alarms, particularly the way alarms were customized, also held strong opinions about customization. Finally, nursing "style" was an overall approach to nursing care that reflects nurses' personality and values. Many nurses described customization as important to them because they liked to be in control, but said that some nurses on the units were "lax" in their customization practices.

To engage in customization, nurses needed a specific *motivation to customize* and *customization "know-how."* The uniqueness of each patient and the lack of "rules" for customization posed challenges, particularly for less experienced nurses who may have had less robust clinical reasoning skills. Ultimately, nurses' *customization decisions* varied depending on the interaction of unit alarm culture, nurse attributes, motivation to customize, and the nurse's customization know-how.

Integrated Analysis

We integrated the quantitative and qualitative results, examining issues related to both frequency and types of alarms customized. Alarm types and frequencies are listed in Table 1. These results are presented in the following section. For types of alarms customized, we explore in depth high and low heart rate limit alarms, atrial fibrillation and irregular heart rate alarms, and premature ventricular contraction (PVC) alarms.

Frequency of ECG alarm customization. We found that 58.7% of monitors had at least one alarm customized at the time of data collection, but from the nurse interviews, we learned of wide variation in the frequency with which individual nurses customized alarms. Some nurses did not customize alarms for a variety of reasons,

including lack of comfort or a previous bad experience in which an inappropriately customized alarm resulted in a missed event. Negative experiences led some nurses to be more cautious about customizing alarms. One participant explained,

> *Some of the nurses with more experience refuse to turn off any alarm because they've seen so much, and something strange has happened, they've had an acute event that's bizarre and … [they] have PTSD [post-traumatic stress disorder] and refuse to turn off alarms. (P13, line 114)*[1]

Other nurses spoke confidently about the process of customizing alarms but then said they only needed to customize alarms "once a week," "a quarter of the time" or "rarely," because they thought the default settings were generally appropriate for their patients. Still other nurses reported that not only did they customize alarms for every patient they cared for, they would also often customize multiple times throughout the shift due to changes in patient condition. These nurses usually were more experienced and conscientious about reducing alarms. The need to customize alarms regularly was obvious to them.

> *I mean if you're in the room and you're paying attention to your patient, you should be customizing the alarms as the night goes along. (P8, line 100)*

Despite the variation in frequency of customization, nurses were aware that customization was within their scope of practice. However, they generally reported that their main source of education on customization came from their preceptors when they were new nurses. Through these channels, unofficial ground rules about customization

[1] P=study participant number; followed by the line number in the transcript

and words of warning were passed down. The lack of formal education helped to explain variation in customization practices.

Types of ECG alarms customized. The types of alarms nurses customized (Table 3) revealed specific areas in which nurses felt confident and others in which nurses faced more challenges.

High and low heart rate limit alarms. The most commonly customized ECG alarm limit in the quantitative data was high heart rate (n=108), followed by low heart rate (n=62). The median change in high heart rate limit was +10 beats per minute (bpm) (mean 13.7 ± 18.5) and median change in low heart rate was 0 bpm (mean 0.8 ± 6.4). Of the high heart rate alarm changes, 38.0% (n=41) were within ±10 bpm of the default setting (120 bpm). High heart rate limits ranged from 110-250 bpm. Of the low heart rate limit changes, 83.9% (n=52) were within ±10 bpm of the default setting (50 bpm). Low heart rate limits ranged from 30-80 bpm. About half of the monitors reviewed in the medical ICU (52.4%) and surgical ICU (50.0%) had heart rate high and/or low alarm limits customized, compared with only 32.4% in the cardiac unit.

We noted considerable variation in the qualitative data on how nurses described setting heart rate alarm limits and how comfortable they felt in changing the limits. Some newer nurses (either new to nursing or new to the unit) were challenged by the lack of explicit rules for customization. Although they understood that good clinical reasoning was required for customization, they lacked confidence in this practice skill or lacked awareness of the practice norms of the unit. One nurse explained how this contributed to variation in heart rate limit settings.

> *I think if you gave the same patient to a few different nurses they might [set] the limits similar but different by a little bit. So, it's not really a cut and dry rule … I wish there was a rule, but there's not really a rule, like … if the patient heart rate has been in the 70s, put the goal plus and minus 20 beats … it's not really like that. It's more just based on your judgment and what you think are the anticipated concerns for this particular patient ... you should change it based on your comfort and everyone is a little bit different (P14, lines 94-96)*

To deal with this, some nurses relied on more experienced nurses, orders, and the care team to help determine what parameters were acceptable for their patient:

> *… it's up to the discretion of the nurse because, in reality we're responsible for monitoring our patient, I personally just like to give a once over with the physician who's on, or the ARPN or PA who's on, and say, '… your patient is tachycardic or bradycardic, this is how low or high they've been … do you want to know it's up over the 130s?', and then I kind of set my parameters from there (P11; line 40)*

In contrast, experienced nurses described relying on their own knowledge of the patient and goals of care for customization decisions; there was no one set of rules for customizing that could be applied to every patient situation. One expert nurse described the assessment required for customizing for a very low heart rate, where slight changes can be consequential.

> *If my patient comes in for a complete heart block, their heart rate is chronically in the 20s or 30s, and they're maintaining their blood pressure and they're coherent and they're hemodynamically stable, if their heart rate is 25 and they're OK and they've been OK like that for several hours for me, I will drop my parameter to 24.*

I mean that's how narrow that margin is going to be. Because maybe their heart rate is OK at 25, but maybe they won't be OK at 24. (P8, line 66)

Of the heart rate alarm limit changes in the quantitative data, only 30 monitors had both the high and low heart rate limits customized; 78 monitors had the high but not low heart rate limit customized, and 32 had the low but not high heart rate limit customized. Of the 140 monitors with a high and/or low heart rate limit customized, 115 monitors (82.1%) had heart rate alarm limits that spanned a wider range than the default setting, and 21 monitors (15.0%) had heart rate alarm limits that were narrower than the default setting. One nurse explained that widening and narrowing alarm limits may relate to nurses' experience level:

I think maybe newer nurses, who one would hope would be kind of nervous, would be the ones to really keep tight alarm parameters. They want to know everything. And then some of the more experienced ones are willing to make the parameters wider. I think all nurses are equally as likely to adjust their alarms unless they don't care, but I mean, there are not many of those. I think all nurses are willing to adjust their alarms to their preference. Some just are more confident and say, 'no, I don't need to know that, I can turn that alarm off.' Whereas newer nurses [think] well what if X, Y, and Z. (P26; line 68)

The widest span was a patient whose high heart rate limit was set for 250 bpm and low heart rate limit was set for 50 bpm. In the qualitative data, only one nurse noted the potential importance of adjusting high and low heart rate limit alarms together. She explained:

> *I would increase [the low heart rate limit] to probably 80 if I have someone running in the 100's to 110's. I wouldn't really let it go that low, I'd want to know if he dropped, if that patient dropped … (P4, line 68)*

This participant thought it would be clinically relevant to know if the patient dropped from 110 bpm to 80 bpm, rather than the default low heart rate limit of 50 bpm. However, the quantitative data showed that most nurses did not change high and low heart rate parameters together.

Another problem was that some nurses were not familiar with the default alarm settings, even for the most commonly customized alarms, such as heart rate. Misconceptions included that the default settings were "normal" heart rate values of 60-100 bpm (the default settings are 50-120 bpm), or that there were no default settings and the settings always carried over from the previous patient in that bed spot. Lack of knowledge was found in nurses of all experience levels.

Atrial fibrillation and irregular heart rate alarms. The most commonly deactivated alarm types in the quantitative data were irregular heart rate (n=70, 23.5%) and atrial fibrillation (n=58, 19.5%). On 54 monitors (18.1%), both irregular heart rate and atrial fibrillation alarms had been deactivated. These findings were consistent with qualitative findings, in which almost all nurses reported atrial fibrillation as one of the alarms they most commonly customized. They expressed comfort with deactivating atrial fibrillation and irregular heart rate alarms for patients in chronic atrial fibrillation, because the condition is so common among patients and usually requires no intervention.

However, new onset atrial fibrillation presented a challenge, particularly for newer nurses. Once they became aware that the patient was in atrial fibrillation, they did not want a constant alarm to sound. However, they did want to know if the patient went in and out of atrial fibrillation. One nurse explained that she was concerned that she would forget to put the alarm settings back once the condition resolved.

> *I guess what I'm trying to say is one of the challenges is finding the appropriateness of turning off certain alarms … for example, going back to the a-fib [atrial fibrillation] one, if they come out of it, then you have to remember, ok … they converted to sinus, let me put the a-fib [alarm] back on so that if they do go back into it, then I'll know ... (P16; line 18)*

Particularly among newer nurses, the concern of forgetting to revert the alarm limits to their previous settings limited their customization of alarms for acute events.

PVC alarms. PVC alarms (R-on-T PVCs, multiform PVCs, run of PVCs, pair of PVCs, PVC rate, ventricular bigeminy, ventricular trigeminy, and ventricular rhythm) were customized in the cardiac ICU more than in the other two units. Of the 40 monitors with at least one PVC alarm customized, 26 (65.0%) were in the cardiac ICU. Additionally, all eight monitors with five or more PVC alarms customized were in the cardiac ICU.

In contrast to atrial fibrillation alarms and heart rate alarm limits, comfort with adjusting PVC alarms was less consistent across interview participants, with the cardiac ICU nurses being most comfortable overall. PVC alarms were defaulted to inaudible alerts in the medical ICU, but were audible in both the cardiac and surgical ICUs. One cardiac ICU nurse explained some of the nuances of customizing PVC alarms.

> *… if your patient just had a STEMI [ST elevation myocardial infarction], they're going to have a reperfusion ectopy, they're going to be throwing PVCs and PACs [premature atrial contractions] … so you can probably turn that off. But what you want to turn on then is if they have a run of like 10 or more PVCs in a row, because you really want to know if they are not getting good cardiac output, but you don't want to know every time they throw one [PVC] … (P22, line 98)*

Nurses in the cardiac ICU were sometimes challenged by the complexity of their patients' rhythms. Some rhythms were not recognized by the monitor, which caused excessive nuisance alarms. Nurses acknowledged that these patients often caused alarm fatigue on the unit because the nurses could not figure out how to customize the alarms effectively, or the monitor configuration did not allow for deactivation of that type of alarm. One nurse with 28 years of experience explained,

> *The frustration with that is sometimes some other arrhythmias mimic V-tach on the monitor. Like, a bundle branch block will look like a wide complex tachycardia and this is where you come into the most frustrating part where you constantly have false alarms but you can't shut off the V-tach alarm … it is so noisy and frustrating. (P5, lines 80-82)*

Although the quantitative data demonstrated that PVC alarms were customized more in the cardiac ICU than in other units, a few participants said that they were less likely to customize arrhythmia alarms *because* it was a cardiac unit. One nurse explained this is "because in the cardiac ICU [it is] more likely [that] the patient is actually going into these rhythms versus in the medical ICU it's more of an artifact."

(P17; line 58). As with the heart rate limits, many nurses could not recall what the PVC default settings were (e.g., the number of PVCs/minute).

Discussion

In this study, we collected quantitative data on the frequency and type of customized ECG alarms, and qualitative data on nurses' clinical reasoning and judgment toward alarm customization in three ICUs. Together, these methods allowed us to understand both the scope and process of customization. The quantitative findings revealed that most monitors had at least one alarm customized, with the most common being heart rate limits, atrial fibrillation, and irregular heart rate. The qualitative findings demonstrated that customization practices vary widely among nurses, and many complex and interacting factors influence their practice. In the following sections, we discuss our findings about frequency and type of customized alarms, and the implications for practice and research.

Frequency of Customization

In this study, almost 59% of monitors had at least one alarm customized. However, this does not mean that 59% of nurses customize, because any alarm customization carries over across shifts unless changed again by another nurse. A few prolific customizers could be responsible for most of the changes. The qualitative findings shed light on how differently individual nurses approach customization, resulting from lack of standardized customization education, and variation in experiences and clinical expertise, among other factors. Expert nurses were typically more comfortable customizing alarms.

Customization frequency is also not an indication of effectiveness or safety of the customization. Default alarm settings may be appropriate for some patients, warranting no changes. Widening alarm limit settings or deactivating alarms in an effort to reduce alarms can be dangerous if an important event is then missed. Improper alarm settings is one of four factors the Joint Commission (2013) has identified as a major contributor to adverse alarm-related events.

Types of Alarms Customized

Heart rate alarm limits were the most commonly customized types of alarms in this study. In another study of customization of heart rate alarm settings, 51% of patients had heart rate alarms customized during their stay, with a median upper limit change of +5 bpm and lower limit change of -1 bpm (Fidler et al., 2017). We found a similar percentage of heart rate alarm customization in the medical (52.4%) and surgical (50.0%) ICUs. We found a median upper limit change of +10 bpm and median lower limit change of 0 bpm. Our findings on variation in the nurses' approaches to customizing heart rate alarms are also consistent with those of Fidler et al (2017); however, they examined customization over the duration of the patient's stay, but only for patients who had a heart rate alarm occur. We looked at customization for all patients regardless of what types of alarms occurred, but at only one time point in the patient's stay.

We were surprised to find that heart rate alarm limits were customized less frequently in the cardiac ICU (32.4%) compared with the other units. Most heart rate limit customization in this study involved changing only the high or low heart rate alarm, rather than adjusting both together. This resulted in wider heart rate limits than the

default settings. It is possible that nurses in the cardiac unit did not want wider heart rate limits as often as nurses in the other units. However, the widest heart rate limit span in this study (50-250) was for a patient in the cardiac ICU. Wider alarm limits create the potential for a clinically significant increase or decrease in heart rate to be missed (relative bradycardia or tachycardia).

Nurses in the cardiac ICU more commonly customized arrhythmia alarms, particularly PVC alarms, than nurses in the other two units. This may be attributable to different patient populations on these units, and to different default configurations for PVC alarms on the units. In the medical ICU, PVC alarms were defaulted to inaudible, while on the other two units, the PVC alarms were defaulted on. We noted a few divergent cases, in which nurses said they customized arrhythmia alarms *less* in the cardiac ICU because they were concerned about missing a relevant arrhythmia. Hesitancy to customize may indicate lack of understanding of how customization can make alarms more relevant, not just serve as a method for suppressing alarms.

Nurses in this study described that the patients creating the most alarms were often those with a complex rhythm or a heart rate well outside the norm. Nurses were frustrated by PVC and ventricular arrhythmia alarms that they could not eliminate by customizing, resulting in excessive clinically irrelevant alarms. This finding is consistent with a study demonstrating that most alarms come from a small number of patients, and are often associated with the presence of a bundle branch block or ventricular pacing (Harris et al., 2017). In our study, better understanding of PVC alarm settings and default settings may have assisted nurses in customizing alarms in some situations, but in others, nurses described that the monitor was misinterpreting a rhythm, creating an

inaccurate alarm. The need for more sophisticated arrhythmia algorithms to address inaccurate alarms has been well-described (Drew et al., 2014). Additionally, some inaccurate alarms may be due to problems with electrodes, which nurses can fix without customizing alarms (e.g., by ensuring proper skin contact).

Implications

Alarm customization is often cited as a promising method for reducing alarm fatigue (Harris et al., 2017; Konkani, Oakley, & Bauld, 2012; Sendelbach & Funk, 2013) and has been included as part of quality improvement interventions (Graham & Cvach, 2010; Sendelbach et al., 2015; Turmell et al., 2017). However, recommendations for how to improve customization practices among nurses are lacking, especially given that customization is a complex process where more is not necessarily better. Little is known about the challenges nurses face customizing alarms, beyond user interface challenges (Fidler et al., 2015; Sowan, Tarriela, Gomez, Reed, & Rapp, 2015). Our study adds insight to this issue, with implications for practice and research.

Because safe and effective customization relies on nurses' clinical reasoning, explicit, guided education is foundational to developing the skill. Most nurses said their only education on use of the monitors and customization was from their preceptor and what they had learned independently. Many of the nurses in our study had some basic knowledge deficits. For example, they could not recall or were not aware of default alarm settings. In addition to basic monitor functionality, education should focus on situations in which customization is potentially confusing. These would include considerations for widening or narrowing alarm limits, adjusting high and low heart rate limits together, deciphering options for PVC alarm adjustments, and managing alarms

during an acute event (silencing, pausing, and/or customizing). Newer nurses in particular found customization stressful, which may be related to lack of situational awareness, clinical experience, familiarity with the monitor and the lack of guidelines to support them. Although customization generally requires nuanced clinical reasoning specific to each patient, there are some exceptions. Clinical guidelines for common issues, such as chronic atrial fibrillation, could be useful for supporting the development of alarm customization clinical reasoning.

Customization education also needs to be unit or patient population specific. On some units, such as cardiac units, PVC alarms may warrant more attention than in the medical ICU, where PVC alarms were defaulted off. Unit debriefings of adverse events related to alarm settings could support nurses' ongoing awareness of customization pitfalls. Units and hospitals should also consider the effectiveness of their alarm customization policies. Although not the case in this study, some institutions restrict nurses' customization of alarms by a certain percentage (e.g., 20% from default) or a certain value (e.g., 10 bpm from default). We found that only about 38.0% of the changes to the high heart rate alarm were within 10 bpm of the default setting. This raises concern that restrictions to customization may not sufficiently account for variation in ICU patient conditions. A recent study on customization in the ICU found that minor adjustments to heart rate did not meaningfully affect alarm rates (Fidler et al., 2017).

In addition to education, advances in technology are also needed to support customization in the chaotic ICU environment. For example, monitor software could indicate that the patient has reverted to "normal" vital sign parameters or a normal

rhythm, and query the nurse to readjust alarm settings or re-activate alarms (Drew et al., 2014). Decision-support software may help nurses like those in this study who were concerned they would forget to change alarms back once an acute situation had resolved.

Future research is needed to explore both education and technology-based interventions that support customization. However, customization is difficult to study because alarm clinical relevance is subjective and difficult to measure (Ruppel, Funk, & Whittemore, 2018). It is also difficult to measure the safety of alarm customization—that is, whether clinically relevant alarms are missed by inappropriate alarm customization. Mechanisms to measure the safety and effectiveness of customization interventions are needed.

Strengths and Limitations

This study has several strengths, including the use of mixed methods to determine how and why nurses customize alarms. We obtained data from three types of ICUs to enhance the representativeness of the sample for different ICU patient populations. However, this was a single-institution study, conducted on units where alarm customization is expected of nurses, which limits generalizability and transferability of findings. Additionally, the interviews were conducted over the same time period as the quantitative data collection, and nurses may have changed their customization practices after participating in the interviews. However, nurses were not aware that we were collecting quantitative data on customization practices, and we described the purpose of the interviews as to understand alarm management in general, not specifically to learn about customization. The customization practices in the

quantitative data were not specific to the nurses we interviewed; however, we believe that our sampling strategies resulted in samples that were representative of the units and could therefore be compared.

We were unable to obtain contextual information for the quantitative variables, because we did not observe nurses actually customizing alarms. We had access only to customization data on ECG alarms in all three units; however, in the interviews, nurses cited other sources of alarms like blood pressure and oxygen saturation as challenging to customize. Future research should examine quantitative data on nurses' customization of non-ECG alarms. Our data were cross-sectional, so we were not able to see how alarm settings were changed over the course of the patient's admission, when they were changed, or by whom. Although beyond the scope of this study, we recognize that customization is only one part of any solution to alarm fatigue and is mainly targeted at reducing clinically irrelevant alarms. Interventions to reduce inaccurate, or false, alarms are also needed.

Conclusion

Customizing alarm settings enhances the clinical relevance of alarms, thereby helping to prevent alarm fatigue. However, nurses' comfort customizing alarms and the frequency with which they customized alarms varies greatly. Development of safe and effective ECG customization practices requires sufficient training on monitor technology use, unit and patient population-specific education, and development of clinical reasoning skills. Once nurses have a foundational understanding of customization, additional decision-support technology for customization will be useful.

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Table 1. Default alarm setting configurations by unit*

	Medical ICU	Cardiac ICU	Surgical ICU
Alarm Limits			
High Heart Rate Limit	120	120	120
Low Heart Rate Limit	50	50	50
VTach Heart Rate	>100 bpm	>100 bpm	>100 bpm
VTach Run	≥5 PVCs	≥5 PVCs	≥5 PVCs
Ventricular Rhythm	>14 PVCs	>14 PVCs	>14 PVCs
PVC Rate or PVCs/minute	>10 PVCs/minute	>10 PVCs/minute	>10 PVCs/minute
SVT Heart Rate	>180 bpm	>180 bpm	>160 bpm
SVT Run	≥5 SVBs	≥5 SVBs	≥5 SVBs
Alarms Activated/Deactivated			
Atrial Fibrillation	On	On	On
R-on-T PVC	Off	On	On
Multiform PVCs	Off	On	On
Ventricular Bigeminy	Off	On	On
Non-Sustained VTach	On	On	On
Run PVCs	Off	On	On
Ventricular Trigeminy	Off	On	On
Ventricular Rhythm	Off	On	On
Pause	On	On	On
Pair PVCs	Off	On	On
Irregular Heart Rate	On	On	On
PVC Rate or PVCs/minute	Off	On	Off
SVT	On	On	On
Missed Beat	On	On	On
Pacermaker not Pace	On	On	On
Pacermaker not Capture	On	On	On

*Alarms that are “Off” still generate inaudible alerts
ICU=intensive care unit; PVC=premature ventricular contraction; VTach=ventricular tachycardia; SVT=supraventricular tachycardia; ECG=electrocardiogram; SVB=supraventricular beats; bpm=beats per minute

Table 2: Patient demographic data for monitors reviewed

	N=278*
Gender	
Male	169 (60.8%)
Female	109 (39.2%)
Race/ethnicity	
White or Caucasian	201 (72.3%)
Black or African American	50 (18.0%)
Asian	4 (1.4%)
Other	20 (7.2%)
Refused	3 (1.1%)
Age in years (mean ± SD; range)	62.8 ± 17.1; 19-90+
Length of stay in hospital in days **Mean ± SD (range)** **Median (IQR)**	 21.3 ± 24.4 (1-184) 12 (6-28)
Length of stay on unit in hours **Mean ± SD (range)** **Median (IQR)**	 255.1 ± 338.8 (15-2616) 142 (60-278)

*Patient data were unobtainable for 20 monitors
SD=standard deviation, IQR=interquartile range

Table 3. Monitor ECG alarm customization by unit

	Medical ICU	Cardiac ICU	Surgical ICU	Total
Total # of monitors reviewed	**147**	**71**	**80**	**298**
≥ 1 alarm customized*†	87 (59.2%)	43 (60.6%)	45 (56.3%)	**175 (58.7%)**
# of alarms customized Mean ± SD (range) Median (IQR)	 1.2 ± 1.4 (0-6) 1.0 (0-2)	 2.7 ± 3.5 (0-14) 1.0 (0-3)	 1.3 ± 1.8 (0-10) 1.0 (0-2)	 **1.6 ± 2.3 (0-14)** **1.0 (0-2)**
≥ 1 Alarm Limit changed†	77 (52.4%)	29 (40.8%)	40 (50.0%)	**146 (49.0%)**
High Heart Rate Limit	58 (39.5%)	18 (25.4%)	32 (40.0%)	**108 (36.2%)**
Low Heart Rate Limit	36 (24.5%)	9 (12.7%)	17 (21.3%)	**62 (20.8%)**
High and/or Low Heart Rate Limit	77 (52.4%)	23 (32.4%)	40 (50.0%)	**140 (47.0%)**
VTach Heart Rate	2 (1.4%)	3 (4.2%)	2 (2.5%)	**7 (2.3%)**
Ventricular Rhythm	0 (0.0%)	5 (7.0%)	0 (0.0%)	**5 (1.7%)**
PVCs/Minute	0 (0.0%)	5 (7.0%)	0 (0.0%)	**5 (1.7%)**
VTach Run	0 (0.0%)	2 (2.8%)	1 (1.3%)	**3 (1.0%)**
SVT Heart Rate	0 (0.0%)	1 (1.4%)	0 (0.0%)	**1 (0.3%)**
SVT Run	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
≥ 1 Alarm Activated/Deactivated*†	39 (26.5%)	36 (50.7%)	23 (28.8%)	**98 (32.9%)**
Irregular Heart Rate	36 (24.5%)	20 (28.2%)	14 (17.5%)	**70 (23.5%)**
Atrial Fibrillation	28 (19.0%)	18 (25.4%)	12 (15.0%)	**58 (19.5%)**
Pair PVCs	0 (0.0%)	24 (33.8%)	7 (8.8%)	**31 (10.4%)**
Multiform PVC	1 (0.7%)	22 (31.0%)	6 (7.5%)	**29 (9.7%)**
PVC/Minute	1 (0.7%)	14 (19.7%)	2 (2.5%)	**17 (5.7%)**
Run PVCs	0 (0.0%)	10 (14.1%)	3 (3.8%)	**13 (4.4%)**
Missed Beat	2 (1.4%)	4 (5.6%)	5 (6.3%)	**11 (3.7%)**
Pause	5 (3.4%)	2 (2.8%)	3 (3.8%)	**10 (3.4%)**
Pacemaker not Capture	2 (1.4%)	7 (9.9%)	0 (0.0%)	**9 (3.0%)**
Pacermaker not Pace	2 (1.4%)	7 (9.9%)	0 (0.0%)	**9 (3.0%)**
Non-Sustained VTach	2 (1.4%)	4 (5.6%)	2 (2.5%)	**8 (2.7%)**
Ventricular Trigeminy	1 (0.7%)	6 (8.5%)	0 (0.0%)	**7 (2.3%)**
Ventricular Bigeminy	0 (0.0%)	6 (8.5%)	0 (0.0%)	**6 (2.0%)**
Ventricular Rhythm	1 (0.7%)	1 (1.4%)	1 (1.3%)	**3 (1.0%)**
R-on-T PVC	0 (0.0%)	3 (4.2%)	0 (0.0%)	**3 (1.0%)**
SVT	1 (0.7%)	1 (1.4%)	0 (0.0%)	**2 (0.7%)**

*Note that these indicate whether alarms were customized from unit default settings—PVC and some ventricular arrhythmia alarms are defaulted *Off* in Medical ICU and *On* in Cardiac and Surgical ICUs (see Table 1)

† Percentages are column percent; percentages do not total 100 because alarm categories are not mutually exclusive

PVC=premature ventricular contraction; VTach=ventricular tachycardia; SVT=supraventricular tachycardia; ECG=electrocardiogram; SVB=supraventricular beats; SD=standard deviation; IQR=interquartile range

Table 4. Nurse interview participant demographics

	N=27
Age in years (mean ± SD; range)	38.3 ± 11.4; 24-59
Gender	
Female	25 (92.6%)
Male	2 (7.4%)
Unit	
Cardiac ICU	12 (44.4%)
Medical ICU	9 (33.3%)
Surgical ICU	6 (22.2%)
Highest level of nursing education	
Associate Degree	2 (7.4%)
Bachelor Degree	25 (92.6%)
Years working as a nurse **Mean ± SD (range)** **Median (IQR)**	 14.2 ± 10.7 (1-35) 13 (4-23)
Years working in ICU **Mean ± SD (range)** **Median (IQR)**	 10.5 ± 9.5 (0.5-28) 7 (2-18)
Years working on current unit **Mean ± SD (range)** **Median (IQR)**	 8.8 ± 8.8 (0.5-28) 5 (2-16)
Shift worked	
Day	14 (51.9%)
Night	4 (14.8%)
Rotate	9 (33.3%)
Status	
Full-time	21 (77.8%)
Part-time	6 (22.2%)

ICU=Intensive care unit, SD=standard deviation, IQR=interquartile range