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Research and Applications

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Optimizing Best Practice Advisory alerts in electronic medical records with a multi-pronged strategy at a tertiary care hospital in Singapore

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ABSTRACT

Objective: Clinical decision support (CDS) alerts can aid in improving patient care. One CDS functionality is the Best Practice Advisory (BPA) alert notification system, wherein BPA alerts are automated alerts embedded in the hospital's electronic medical records (EMR). However, excessive alerts can change clinician behavior; redundant and repetitive alerts can contribute to alert fatigue. Alerts can be optimized through a multipronged strategy. Our study aims to describe these strategies adopted and evaluate the resultant BPA alert optimization outcomes.

Materials and Methods: This retrospective single-center study was done at Jurong Health Campus. Aggregated, anonymized data on patient demographics and alert statistics were collected from January 1, 2018 to December 31, 2021. "Preintervention" period was January 1–December 31, 2018, and "postintervention" period was January 1–December 31, 2021. The intervention period was the intervening period. Categorical variables were reported as frequencies and proportions and compared using the chi-square test. Continuous data were reported as median (interquartile range, IQR) and compared using the Wilcoxon rank-sum test. Statistical significance was defined at $P < .05$.

Results: There was a significant reduction of 59.6% in the total number of interruptive BPA alerts, despite an increase in the number of unique BPAs from 54 to 360 from pre- to postintervention. There was a 74% reduction in the number of alerts from the 7 BPAs that were optimized from the pre- to postintervention period. There was a significant increase in percentage of overall interruptive BPA alerts with action taken (8 [IQR 7.7–8.4] to 54.7 [IQR 52.5–58.9], P-value $< .05$) and optimized BPAs with action taken (32.6 [IQR 32.3–32.9] to 72.6 [IQR 64.3–73.4], P-value $< .05$). We estimate that the reduction in alerts saved 3600 h of providers' time per year.

Conclusions: A significant reduction in interruptive alert volume, and a significant increase in action taken rates despite manifold increase in the number of unique BPAs could be achieved through concentrated efforts focusing on governance, data review, and visualization using a system-embedded tool, combined with the CDS Five Rights framework, to optimize alerts. Improved alert compliance was likely multifactorial—due to decreased repeated alert firing for the same patient; better awareness due to stakeholders' involvement; and less fatigue since unnecessary alerts were removed. Future studies should prospectively focus on patients' clinical chart reviews to assess downstream effects of various actions taken, identify any possibility of harm, and collect end-user feedback regarding the utility of alerts.

LAY SUMMARY

Electronic medical records (EMR) are used in hospitals to improve patient care. One way is through providing clinical decision support (CDS) alerts to healthcare professionals, which are triggered at different time points in the clinical workflow. While these alerts can be helpful, a high volume of alerts can cause alert fatigue in clinicians, leading to clinicians overriding or ignoring these alerts. This article details how our local institution adopted a multipronged strategy to reduce the volume of alerts, including feedback from healthcare providers, a multidisciplinary committee, an embedded data visualization tool in the EMR, data review, clinical governance, and alert optimization according to a framework (CDS Five Rights framework). With the strategies implemented, there was a significant reduction in the number alerts by 59.6% despite a manifold increase in the total number of BPAs. Also, the percentage of alerts that healthcare professionals acted on rose from 8% to 54.7%. Improved alert compliance was likely multifactorial—due to decreased repeated alert firing for the same patient; better awareness due to stakeholders' involvement; and less alert fatigue as unnecessary alerts were removed.

Key words: alerts, Best Practice Advisory alerts, clinical decision support, electronic medical records

INTRODUCTION

Electronic medical record (EMR) and computerized provider order entry (CPOE) systems are widely used to facilitate patient care. One important component of the EMR and CPOE systems is the clinical decision support (CDS).[1] CDS comes in the form of computerized alerts, and is provided in various ways, such as interruptive "pop-up" alerts, information displays, links and targeted highlighting of relevant data. When CDS is provided to clinicians within clinical workflows

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as actionable, patient-specific recommendations at the time and location of decision making, CDS has been shown to significantly improve clinical practice in over 90% of randomized controlled trials.[2]

One CDS functionality is the Best Practice Advisory (BPA) alert notification system, wherein BPA alerts are automated alerts embedded in the hospital's EMR or CPOE system. BPA alerts help to facilitate communication of information to healthcare providers and guide clinical practice. BPA alerts can be "interruptive" or "in-line noninterruptive"; the former requires clinicians to acknowledge the alert before proceeding. These alerts are highly versatile and can be triggered for display at various times in the clinical workflow. For example, alerts can remind clinicians to fill in required documentation, notify them about the high-risk conditions that may affect clinical decisions, and notify of potential drug interactions while ordering medications. Implementation of new BPAs have been linked to improved clinical workflows in previous studies.[3,4]

While CDS alerts can aid in improving patient care and can change clinician behavior, redundant and repetitive alerts can contribute to alert fatigue, which can consume time and mental energy of physicians.[5] Additionally, when clinicians exhibit alert fatigue, alerts are unlikely to be read nor considered, and may be overridden as a matter of habit. A systematic review identified the most common barrier to alert acceptance was the large number of irrelevant alerts that were presented to clinicians.[6] A previous review investigating alert overrides in hospitals found that drug safety alerts were overridden in 49–96% of cases.[7] Thus, alert fatigue may result in missing or overlooking potentially important alerts that could have prevented harm to the patients.[8–10]

Furthermore, alerts can have significant costs, such as the time taken by clinicians to process them. One study found that drug-drug interaction alerts took a median of 8 seconds to process each alert.[11] Authors estimated that with an estimated cost of around USD 108 per hour per physician at the lower range, each alert yielded a time cost of USD 0.24 per physician per drug-drug interaction alert.[12] Hence, with high alert override rates, there is significant time cost in engaging these alerts, resulting in lost productivity.

Therefore, the EMR has to be optimized to provide a well-functioning system for clinicians to provide expedited and high-quality care to the patients. The high override rates reported in the literature suggest that alerts need to be improved to increase their effectiveness and acceptance, and reduce problems associated with alert fatigue.[13] While optimizing alerts is important to prevent alert fatigue, this must be balanced against the risks of removing perceived safety measures. One possible option is to monitor the rate of clinical adverse events while alert optimization is being performed.[14]

A review by Von Dart et al analyzed the strategies employed by hospitals to select and/or optimize alerts.[15] The most common intervention was the use of a multidisciplinary committee to optimize alerts. Other common interventions were the use of alert data (alert firing rates, alert override rates) and visual dashboards to monitor and evaluate alerts,[14,16] and the use of literature, drug references, and clinician feedback to decide on alert changes and track outcomes after changes were made. While previous studies have shown a reduction in CDS alerts with various optimization strategies,[14,17–19] the majority of studies are from the United States and focused on medication-related CDS alerts.[17–19] Despite the widespread adoption of BPAs in EMR systems, to our knowledge, there is only 1 publication describing strategies adopted to optimize these alerts, and the outcomes and effectiveness of these strategies.[16]

At our local institution, we aimed to optimize existing BPA alerts using rigorous governance, data review and visualization using a system-embedded tool, combined with the CDS Five Rights framework, and ensure that any new alerts are being introduced following a similar process. The aim of our study is to describe the strategies adopted and evaluate BPA optimization outcomes in our local institution using a multipronged approach.

METHODS

Context

Jurong Health campus (JHC) is a healthcare cluster consisting of a 700-bedded tertiary care public hospital (Ng Teng Fong General Hospital, NTFGH), a 400-bedded community hospital (Jurong Community Hospital, JCH), and outpatient clinics. JHC is part of larger cluster of hospitals and clinics under the umbrella of National University Hospital Systems (NUHS). JHC completed an enterprise-wide go-live of the Epic® EMR system in July 2015. Over the next few years, our institution observed a significantly high volume of BPA alerts being fired and dismissed, a trend similar to other organizations internationally.[3–5] As such, there were concerns raised regarding the risk of desensitization and alert fatigue due to alert overload. In early 2019, resources were finally available to optimize BPAs, where we started to monitor and optimize these alerts using reports generated by medical informatics (MI) reporting team. Subsequently, in early 2020, we had access to a system-embedded BPA data visualization tool, called Slicer Dicer®, embedded within the Epic® EMR system.

Intervention

We chose an ongoing process of evaluation and optimization of overall BPAs, rather than a single instance of alert optimization. Our approach was to optimize existing BPAs, but also ensure that any new BPAs being introduced would follow a similar governance process. Our approach consisted of the use of alert data, a multidisciplinary committee, informal clinician feedback and stakeholder engagement, and the use of literature and drug references. This is similar to the strategies described previously in the literature[15,16]:

1) Alert data and visualization to facilitate review and monitoring of BPA alerts—in the first step of our evaluation, we used alert data gathered using static reports generated by the MI team. Since February 2020, the embedded data visualization tool in the EMR, which is a self-service tool, has made the monitoring and targeted optimization of alerts easier by mitigating the slow, manual process of MI staff running static queries. The target alerts for optimization were prioritized in accordance with the volume of interruptive alerts, usefulness of the alerts, as well as the alert override rates.
2) Governance through a multidisciplinary team—this has been the most commonly used approach in previous studies of CDS alert optimization, including BPA alerts.[15] A multidisciplinary CDS group was formed in early 2019 as part of NUHS-wide EMR migration to EPIC® enterprise. Our multidisciplinary team structure

is similar to the only published study targeting BPA optimization,[16]—MI staff, clinicians who are also MI officers (such as the Chief MI Officers), clinicians, and pharmacists from hospitals within NUHS. However, due to competing training priorities and shorter periods of clinical postings, it was challenging to include junior doctors. Therefore, junior physicians were not part of our multidisciplinary group.

The CDS group monitored and evaluated the existing alerts. Informal feedback from end-users was sought regarding usefulness of existing alerts. Thereafter, stakeholders were engaged to discuss and reach a consensus regarding alert optimization. These stakeholders included institutional ethics leads, infectious disease experts, clinicians, and the medication safety committee for the respective alerts. We sought to involve stakeholders in the decision-making process, since previous studies have suggested that end-user involvement in CDS development and implementation significantly improves CDS acceptance.[15,20–22] Alerts that did not serve the intended purpose were encouraged to be disabled and alternative EMR tools were considered achieve the objectives.

We used a similar governance process for all new alerts that were introduced during this time period. Guidance was provided to MI builders and clinician stakeholders on how to present to the CDS Committee for approval request:

- Every new BPA request required a clinical leader. Ownership was essential to ensure that the alert met the intended ask, fit clinicians' daily workflow, and could be re-evaluated and optimized post-implementation. An integral step of the governance process was also for the BPA requestors and builders to have a clear post-implementation plan with potential metrics or data to evaluate.
- Harmonization of alerts amongst the various institutions within NUHS, in view of perceived advantages such as easier maintenance of the build for the MI team, and shared benefits of the alert's intent to all users across NUHS.
- BPA requests with some evidence that the alert will have a positive impact on safety, efficiency, quality, workflow or other organizational goals would be ranked higher
- Requestors were guided towards best practices ("CDS Five Rights" framework) to reduce alert fatigue, which is elaborated below.[23]

To inspire the MI builders, exceptional optimization approaches and BPA designs were showcased, which ultimately helped to re-enforce the governance standards and recommended strategies.

These governance standards and principles formed the stepping stones to the eventual development of a standardized BPA request evaluation form, which was implemented in April 2021 (Supplementary Appendix 1). The BPA request evaluation form, which followed a scoring system, allowed MI builders and the committee to prioritize build requests in the event there were many requests from stakeholders. Higher scores were given when the above-mentioned principles were adhered to.

3) Literature review and drug references were used to justify decisions on changing alerts, where applicable.

"CDS Five Rights" framework

As there was no data in the literature to suggest the optimal volume of alerts,[16] the initial goal of our institution was to reduce the overall volume of alerts without a specific target. The target alerts for optimization were prioritized in accordance with the volume of interruptive alerts, usefulness of the alerts, and alert override rates. We identified the following interruptive BPAs during the intervention period—4 allergy-related BPAs, 1 CAUTI BPA, 1 smoking cessation BPA, and 1 Code Status BPA. We followed the "CDS Five Rights" framework, which has been proposed as a best practice framework for appropriate CDS options.[23] The "CDS Five Rights" framework states that to provide benefits, CDS interventions must provide:

- the right information (evidence-based guidance, response to clinical need)
- to the right people (entire care team—including the patient)
- at the right points in workflow (for decision making or action)
- through the right channels (eg, EHR, mobile device, patient portal)
- in the right intervention formats (eg, order sets, flow sheets, dashboards, patient lists)

The right information—one commonly cited reason for high alert override rates has been a lack of relevance and specificity.[6,24,25] Therefore, we identified high volume alerts that were not relevant in our local clinical context and aimed to limit such alerts. One such alert, the "Code Status" BPA, focused on documentation of code status of every newly admitted inpatient and prompted users to key in the "full code status" for every patient. After discussions with stakeholders, we reached a consensus that unless documented otherwise, every admitted inpatient should be considered full code; there should be no requirement to prompt clinicians for explicit documentation. After consultation with institutional ethics leads, this alert was turned off completely given low acceptance of the alert. Another set of BPAs optimized were the BPAs focused on reviewing patient allergies. These alerts would be triggered when a clinician places any new order. We suppressed these alerts from being triggered when clinicians placed non-medications orders (eg, consult requests, ordering blood tests).

To the right people—we evaluated and optimized BPAs by ensuring that the specific alerts only fire to applicable roles and at specific provider locations (eg, emergency department, ambulatory clinics, versus inpatient settings) for prioritized alerts. One example is that allergy-related alerts were firing for a wide range of clinical team members including nurses and allied health members. However, nurses and allied health members do not have allergy reconciliation and verification rights in the local context. With stakeholder engagement, nurses and allied health members were then excluded from this alert firing. We also identified that dental providers were erroneously excluded from seeing this alert. Therefore, the alert design was modified to include dental providers.

At the right points in workflow (for decision making or action)—historically, in cases where the patient's allergies have not been reviewed, allergy alerts would be triggered at "open order entry activity or open order set, or pathway." In our local EMR workflow, clinicians may navigate to the

orders activity only for viewing (as part of patient review), rather than placing any clinical orders. We optimized for the allergy review alerts to fire only at "enter order." The next step we took was to modify the trigger of the interruptive allergy alerts to fire only when users were entering medication orders, if they had yet to reconcile the allergies. This prevented the indiscriminate triggering of allergy alerts when users entered any orders, including nonmedication orders.

Through the right channels (eg, EMR, mobile device, patient portal)—one alert that was deemed better suited for other channels was the "CAUTI" (catheter-associated urinary tract infection) BPA. This alert would trigger if a patient continued to have a urinary catheter in situ after more than 3 days of inpatient stay. This alert reminded clinicians to either remove the urinary catheter or to acknowledge for presence of urinary catheter as per an evidence-based list of reasons. During alert monitoring, we discovered that this alert had a high override rate. The reasons were multifactorial, such as alerting at wrong point in the workflow, or that the alert interface involved too much information. We engaged infectious disease experts and stakeholders, who opined that the desired clinical goal could be better achieved by clinical education and that this alert was not required. Therefore, this BPA was removed.

In the right intervention formats—we modified allergy alerts to trigger as noninterruptive alerts in the navigator, where if users followed the correct workflow in the navigator section, they could reconcile the allergies first, thereby reducing firing of interruptive alerts downstream in the workflow. Users were also educated on this workflow.

Data collection

This study was approved by the Institutional Review Board, DSRB 2022/00099. The BPA alerts have been continually optimized since early 2019. Because of the manifold nature of these changes, many alerts had changes implemented in a stepwise fashion; therefore, there are no specific implementation dates for alert-specific changes.

We collected data from January 1, 2018 to December 31, 2021. We used a 1-year period from January 1, 2018 to December 31, 2018 as "preintervention" and January 1, 2021 to December 31, 2021 as "postintervention" periods. We considered January 1, 2019 through to December 31, 2020 as the intervention period.

We collected data on patient demographic characteristics including number of patients admitted, age, and gender. We reviewed alert statistics such as total number of interruptive alerts and total number of optimized interruptive alerts. These were examined for various provider groups—physicians, nurses, pharmacists, and allied health team members. We also analyzed percentage of alerts with action taken (an action taken by the user referred to any action taken, eg, "accept," follow recommended clinical action apart from "Cancel," "dismisses the BPA," and "Acknowledge [no action taken]"). Additionally, we reviewed the time clinicians spend on BPA alerts from alert pop-up until any action taken (also known as dwell time—a measure of the time taken to resolve the interruptive alerts).

The 7 interruptive BPAs (4 allergy-related BPAs, 1 CAUTI BPA, 1 smoking cessation BPA, and 1 code status BPA) were modified according to the "CDS Five Rights" framework and these BPAs are referred to as "Optimized BPAs," as these BPAs were optimized during the intervention period. BPAs that were not optimized, are referred to as "Nonoptimized BPAs." We collected the total number of unique BPA alerts in the pre- and postintervention periods. There were 54 BPAs available in the preintervention period compared with 360 BPAs available in the postintervention period.

As suggested previously, the risks of removing perceived safety measures must be balanced against those of widespread alert fatigue. As a balancing measure, we reviewed CAUTI rates and serious safety events reported in association with interruptive BPA optimization. At our institution, we define serious reportable event (SRE) as an error that may have contributed to or resulted in permanent patient harm.

Statistical analysis

Categorical variables were reported as frequencies and proportions and compared using the chi-square test. Continuous data were reported as median (interquartile range, IQR) and compared using the Wilcoxon rank-sum test. Statistical significance was defined at $P < 0.05$.

RESULTS

In 2018, there were 345 134 patients seen, of which 54.5% were males, and the average age was 64.5 ±19.0 years (standard deviation). In 2021, there were 342 296 patients, of which 56.4% were males, and the average age was 63.4 ±19.3 years. Outpatient visits encompassed 17.7 ±4.0% of the BPA alerts fired.

Parallel fixes of the 7 optimized BPAs were conducted at the same time during the intervention period.

Preintervention, there were an average of 2480 distinct users, with 570 doctors, 1501 nurses, 93 pharmacists, and 145 allied health users. Postintervention, there were an average of 2878 users, with 690 doctors, 1467 nurses, 84 pharmacists, and 215 allied health users.

Postintervention, there was a significant reduction of 59.6% in the total number of interruptive BPA alerts per month (Table 1]). All clinical groups experienced a significant reduction of interruptive alerts (Table 1). We observed a significant increase in percentage of interruptive alerts with action taken across all provider groups (Table 1).

Furthermore, the number of interruptive alerts from optimized BPAs reduced from 241 308 in the preintervention period to 61 968 in the postintervention period, a 74.3%% reduction (*P*-value <.00005) (Table 2). A similar trend was seen across all provider groups. We further analyzed the proportion of alerts with action taken separately for the interruptive alerts from optimized BPAs and observed a significant improvement across all provider groups (Table 2).

We collected information on dwell time for various provider groups for the postintervention period only since this information for the preintervention period was not available. The mean overall dwell time was 6.1 ±27.2 s.

Finally, there was no SRE where BPA optimization was a contributing factor. In our institution, the rates of CAUTI are only tracked in the intensive care unit (ICU) and JCH. Preintervention, in 2018, the rates of CAUTI were 3.39 infections per 1000 catheter days and 2.68 infections per 1000 catheter days in ICU and JCH, respectively. Postintervention, in 2021, the rates of CAUTI were 4.26 infections per 1000 catheter days in the ICU ($P = .68$), and 3.57 infections per 1000 catheter days in JCH ($P = .386$).

Table 1. Number of Interruptive alerts per month and percentage of alerts with action taken

Number of interruptive alerts per month and percentage of alerts with action taken	*Preintervention median (Q1, Q3)*	*Postintervention median (Q1, Q3)*	*P-value*
Overall	297 178 (275 073, 316 102)	120 093 (115 503, 122 694)	<.00005
(% action taken)	8.0 (7.7, 8.4)	54.7 (52.5, 58.9)	<.00005
Physicians	159 470 (146 464, 167 638)	81 603 (78 890, 83 658)	<.00005
(% action taken)	9.1 (8.3, 9.2)	63.1 (60.9, 67.9)	<.00005
Nurses	80 425 (75 095, 95 936)	13 090 (12 195, 13 889)	<.00005
(% action taken)	6.0 (5.2, 6.3)	27 (26.3, 28.1)	<.0003
Pharmacists	18 404 (18 076, 18 943)	10 708 (10 017, 11 217)	<.00005
(% action taken)	11.3 (10.4, 11.6)	27 (25.6, 30.0)	<.0003
Allied health	3598 (3330, 3790)	481 (423, 641)	<.00005
(% action taken)	1.5 (1.38, 1.9)	17.9 (12.7, 20.1)	<.0003

Table 2. Number of interruptive alerts from optimized BPAs per month and percentage of these alerts with action taken

Number of interruptive alerts from optimized BPAs per month and percentage of alerts with action taken	*Preintervention median (Q1, Q3)*	*Postintervention median (Q1, Q3)*	*BPA volume reduction* (%) *P-value*
Overall	241 308 (217 534, 243 982)	61 968 (55 723, 65 211)	74.3%
(% action taken)	32.6 (32.3, 32.9)	72.6 (64.3, 73.4)	<.00002
Physicians	125 821 (120 399, 126 299)	46 514 (42 679, 48 554)	63.0%
(% action taken)	45.3 (45.2, 46.4)	78.7 (69.3, 80.0)	<.00003
Nurses	69 246 (53 321, 71 015)	183 (157, 209)	99.7%
(% action taken)	0.008 (0.006, 0.01)	97.6 (90.9, 100)	<.0003
Pharmacists	15 054 (14 943, 15 348)	8009 (7945, 8169)	46.8%
(% action taken)	0.02 (0.007, 0.03)	15.5 (15, 20.6)	<.0003
Allied health	3382 (3368, 3407)	221 (195, 242)	93.5%
(% action taken)	0.06 (0.02, 0.14)	28.2 (16.2, 34.2)	<.00003

DISCUSSION

Our results highlight that our institution achieved a reduction in overall interruptive alert volume and improved action taken rates, despite manifold increase in the number of unique BPAs. We utilized a multipronged strategy of clinical governance with stakeholder involvement, data visualization to identify targets, and adherence to the CDS "Five Rights" to optimize not only the existing alerts, but also ensured that any new alerts being introduced followed a similar process. Despite a considerable increase in the number of unique BPAs in the EMR from 54 to 360 in the postintervention period, our results are a testimony to the rigorous governance process that was followed.

The cognitive burden of excessive alerts cannot be underestimated. Previous studies have suggested that the physician's prior dismissal of alerts leads to their increased habit strengths.[26] Furthermore, additional alerts resulted in a reduced responsiveness to additional alarms, which also led to numerous deleterious effects such as interruptions on the user's primary task, and errors in dispensing and administering errors.[27–29] It is important that we are wary of the adverse effects that a high alert volume can have on healthcare professionals, and seek to optimize alerts in the EMR.

Our institution adopted strategies similar to those previously described in the literature.[14–16] Our institution achieved a significant reduction of 59.6% in number of interruptive alerts in the postintervention period. In comparison to the only other publication on optimization of BPAs, Chaparro et al[16] used the following strategies—redesigned alerts (Nielson's usability heuristics), tailored them to clinician type and modified alerts based on provider feedback. Their approach reduced alerts from 7250 to 4400 per week (39% reduction). One of the studies utilized Lean Six Sigma and the Define-Measure-Analyze-Improve-Control cycle methodologies to prioritize high-volume alerts for review and achieved 28% reduction in CPOE alerts.[30] A possible explanation to a higher reduction in our institution may be due to an initially large volume of redundant alerts in the preintervention period.

With the reduction in the volume of alerts, and alongside a clinician-led optimized workflow according to the "CDS Five Rights" framework, there was an increase in alert action taken rates, and with less alerts, it could have been easier to take actions on alerts. This is further demonstrated as our institution only optimized 7 BPAs during the intervention period, while our institution introduced many more BPAs each year. Despite the increasing number of BPAs, our institution managed to improve the overall volume of BPA alerts while still achieving higher alert action taken rates.

Additionally, our BPA optimization efforts were co-led by informatician clinicians, who were end-users themselves, where previous studies have also suggested that end-user involvement in CDS development and implementation is known to significantly improve CDS acceptance.[15,20–22] Hence, our approach may have contributed to better acceptance for the change process.

Furthermore, our institution also utilized a visualization tool which is embedded within our EMR. One of the major challenges limiting the optimization of CDS systems is the extensive manpower often involved in manually reviewing alert and response appropriateness. Previous studies have

suggested that the use of dashboards has assisted hospital CDS committees to quickly identify alert types to target for optimization.[14,15] Instead of creating a custom dashboard, we utilized existing tools to better focus our limited resources towards optimizing alerts that would provide the most benefits. This data visualization tool equipped us with a highly interactive and comprehensive self-service tool to analyze the alert dataset in near real-time, therefore mitigating the slow manual process of MI staff needing to run static queries. While we did not use this tool in a novel way, it was part of our multi-pronged approach towards BPA optimization.[14–16]

Overall, the reasons for improved alert compliance were likely multifactorial—due to decreased repeated alert firing for the same patient as the number of alerts per patient reduced from 9.8 to 4.1; better awareness due to stakeholders' involvement; and less fatigue since unnecessary alerts were removed. However, we do acknowledge that the exact reasons of improved alert compliance are unclear, and future studies should examine end-user feedback and behavior.

At our institution, we started the alert optimization almost 42 months after EPIC® implementation. This is compared to an average of 6–15 months, and even up to 13 years, in previous publications.[14,16,17,21] This wide variation may be due to the difficulties associated with analyzing the large amount of BPA data initially as static queries were used and competing priorities while stabilizing a newly inducted EMR systems with limited resources.

One strength of our study is that we evaluated other important outcomes related to BPA optimization, rather than just the change in number of alerts. First, we observed a significant improvement in number of alerts with action taken, for both optimized and non-optimized BPAs. This may be explained by decreased burden of nuisance alerts ("noise") might have improved providers' response to the alerts that remain in the system ("signal"). Interestingly, we observed this pattern despite no significant change in number of alerts per user among non-optimized alerts.

Second, we assessed "dwell time," a measure of the time taken to resolve the interruptive alerts. Our study found an overall average dwell time of 6.1 s. Other studies have found a median of 1.3–1.5 s per interruptive alert among healthcare providers,[31] and 8 s for interruptive drug-drug interaction alerts.[11] With a significant reduction in interruptive alerts, there would have been a significant reduction in the time viewing redundant interruptive alerts. By reducing the median monthly interruptive alerts from 297 178 [IQR 275 073; 316 102] to 120 093 [IQR 115 503; 122 694], this would reduce screentime by 300 h per months of providers' time on addressing alerts, where this time could have been channeled to more productive activities. This would have resulted in an approximate savings of SGD 150 000 per year at our institution, taking into consideration renumerations for various clinician groups. However, it is important to bear in mind that the time savings may not necessarily have been translated to more efficiencies.

Finally, we monitored the SRE events where BPA optimization could have been related to the event. To our knowledge, after discussion with our safety officers, there were no SREs reported during the entire period. Similarly, there was no statistically significant change in monitored CAUTI rates.

However, we do acknowledge that the full extent of adverse events is difficult to assess and beyond the scope of our work. We only monitored the reported events, which usually represent serious events only. There may be other related minor events/harm that was not reported or not deemed related to BPA changes. Similarly, we did not evaluate individual patient notes to look for such minor adverse events. It is difficult to find the balance between a reduction in alert burden versus the potential for harm to the patient by not displaying an alert and the risk of an adverse event due to a deactivated alert remains.[16]

A further limitation of our study is that this review does not include a comprehensive assessment of clinical outcomes alongside BPA optimization. For example, we did not assess whether users followed through with their actions after addressing the alert. Another limitation is that we did not measure the utility of the alerts, neither did we collect end-user feedback regarding the alerts. Alert fatigue is not only due to the volume of alerts received, but the usability of the alerts. Due to the inherent difficulty in measuring the usefulness of individual alerts, our institution's BPA optimization focused on the reduction of the alert volume, similar to previous studies.[14–16] Also, qualitatively assessing end-user feedback was beyond the scope of this study.

Finally, junior physicians were not part of our multidisciplinary group. Junior physicians are the primary users of CPOE systems and majority of prescriptions are entered into CPOE systems by junior doctors.[13,32] In our institution, junior physicians likewise comprise the largest proportion of any medical team. However, due to competing training priorities and shorter periods of clinical postings, it was challenging to include junior doctors.

CONCLUSION

In summary, our results highlight that a significant reduction in interruptive alert volume and improved action taken rates despite a greater than 6 times increase in the number of unique BPAs, can be achieved through concentrated efforts focusing on governance, data review and visualization combined with ensuring the Osheroff's CDS Five Rights to optimize the alerts. Organizations new to harnessing CDS alerts can also learn from our implementation process and have a robust clinical governance in place at the start. While potentially reducing alert fatigue and financial savings, this reduction in alert volume was not associated with any worse clinical outcomes due to missed alerts. Improved alert compliance was likely multifactorial—due to decreased repeated alert firing for the same patient; better awareness due to stakeholders' involvement; and less alert fatigue as unnecessary alerts were removed. Future studies should be prospective and additionally focus on patients' clinical chart reviews to assess downstream effects of various actions taken, identify any possibility of harm, and collect end-user feedback pre- and post-intervention regarding the utility of alerts.

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AUTHOR CONTRIBUTIONS

Dr Hannah, Dr Amit, Ms Jishana, Mr Hing, and Ms Hermione contributed to the acquisition, analysis, and interpretation of data for the work.

Dr Hannah, Dr Amit, Dr Carmen, Ms Hermione, Dr Jared, Dr Er Luen, and Dr Gamaliel contributed to the conception and design of the work.

Dr Hannah, Dr Amit, and Ms Jishana contributed to the drafting of the work.

Mr Hing, Ms Jishana, Dr Carmen, Ms Hermione, Dr Jared, Dr Er Luen, and Dr Gamaliel contributed to revising the draft for important intellectual content.

All authors contributed to the final approval of the version to be published, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *JAMIA Open* online.

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DATA AVAILABILITY

The data underlying this article will be shared on reasonable request to the corresponding article.

CONFLICT OF INTEREST STATEMENT

None declared.

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