The vulnerabilities of computerized physician order entry systems: a qualitative study

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ABSTRACT

Objective To test the vulnerabilities of a wide range of computerized physician order entry (CPOE) systems to different types of medication errors, and develop a more comprehensive qualitative understanding of how their design could be improved.

Materials and Methods The authors reviewed a random sample of 63 040 medication error reports from the US Pharmacopeia (USP) MEDMARX reporting system where CPOE systems were considered a “contributing factor” to errors and flagged test scenarios that could be tested in current CPOE systems. Testers entered these orders in 13 commercial and homegrown CPOE systems across 16 different sites in the United States and Canada, using both usual practice and where-needed workarounds. Overarching themes relevant to interface design and usability/workflow issues were identified.

Results CPOE systems often failed to detect and prevent important medication errors. Generation of electronic alert warnings varied widely between systems, and depended on a number of factors, including how the order information was entered. Alerts were often confusing, with unrelated warnings appearing on the same screen as those more relevant to the current erroneous entry. Dangerous drug-drug interaction warnings were displayed only after the order was placed rather than at the time of ordering. Testers illustrated various workarounds that allowed them to enter these erroneous orders.

Discussion and Conclusion The authors found high variability in ordering approaches between different CPOE systems, with major deficiencies identified in some systems. It is important that developers reflect on these findings and build in safeguards to ensure safer prescribing for patients.

Keywords: clinical decision support, patient safety, electronic prescribing, workarounds, alerts, medication errors

BACKGROUND AND SIGNIFICANCE

Medication errors are extremely common. According to the Institute of Medicine (IOM), a hospitalized patient experiences on average at least one medication error per day in the United States.1 It is widely acknowledged that computerized physician order entry (CPOE) systems can help prevent medication errors in both inpatient and outpatient settings.2,3 CPOE systems with clinical decision support (CDS) can provide dosing suggestions, eliminate illegible orders, assist with calculations, check for allergies, and monitor for drug-drug interactions.4–7 Recognizing these well-established benefits, the federal government attempted to accelerate their adoption by offering financial incentives to those US hospitals demonstrating meaningful use of electronic health records, including CPOE systems.8 Many studies have concentrated on the effectiveness of internally developed systems from academic centers of excellence,9 but far fewer have evaluated commercially purchased systems in community hospitals even though these vendor-developed applications represent the vast majority of systems today.10

Concerns about harm from the use of CPOE systems have also emerged. One study conducted in a US teaching hospital showed how the use of a system could promote medication error risks in addition to reducing them.11 Examples included fragmented computer screen displays that prevented a coherent view of patients’ medications, failure to differentiate between look-alike drug names, and inflexible ordering formats generating wrong medication orders. Horsky et al.12 revealed how a serious dosing error of potassium chloride resulted from failures in human-computer interaction, such as confusion about on-screen laboratory results review, uncertainty on the part of physicians about how to manage unusual ordering scenarios, and the absence of automated safeguards that help prevent errors. A multinational study by Ash and colleagues9 also found instances where technology seemed to foster rather than reduce the likelihood of errors. Another study showed CPOE systems delivered an overdose of alerts or warning messages to physicians, many of which were felt to be irrelevant or inappropriate.13 Physicians often disregarded these messages, and run the risk of overlooking clinically important alerts as well as those that were considered unimportant.

CPOE systems are constantly evolving, but their safety is dependent not only on how they are designed, but also on how they are implemented and used in clinical practice, and individual institutions have considerable latitude. One study found that about half of event fatal medication errors did not result in a warning, and there was almost no correlation with vendor.14 The IOM Committee report Health IT and Patient Safety: Building Safer Systems for Better Care discussed various safety issues associated with health IT and recommended that specific examples of potentially unsafe processes and risk-enhancing interfaces be shared among the health IT community.15 This committee also called for a more streamlined approach to the reporting of health IT-related adverse events, and for both vendors and users to rectify systemic issues.
We performed detailed testing of the vulnerabilities of a wide range of leading vendor and homegrown, inpatient and outpatient CPOE systems to different types of medication errors. Here, we present the qualitative findings from this large, mixed methods study conducted over 2 years in a broad range of healthcare settings to provide a more comprehensive understanding of human factors design issues and how these could be improved.

**MATERIAL AND METHODS**

As part of a National Patient Safety Foundation-funded project, we approached a range of diverse organizations (e.g., academic medical centers, private medical practices) using different commercial and homegrown CPOE systems across the United States and Canada. Test participants (mostly medical residents or primary care attending physicians, henceforth referred to as “testers”) were identified at each of the 16 sites and asked if they would be willing to participate. Each tester was offered a small remuneration ($100 gift card) for their time.

**Test case scenarios**

The design of test case scenarios has been discussed at length in our previous publication but, in short, we downloaded all 63 040 medication error reports where CPOE systems were considered a “contributing factor” to errors from the USP MEDMARX reporting system between January 2003 and April 2010. A team of pharmacists (M.G.A., J.J.B., A.C.S., M.S.) and a general internist (G.D.S.) manually reviewed a sample of these reports (16.0%, n = 10 060), which included all 191 reports, categorized as E−I (an error that resulted in patient harm) according to the National Coordinating Council for Medication Error Reporting and Prevention classification. A random sample of the remaining A–E category reports (no patient harm caused) were also included. Of note, 98.18% of the errors occurred in Categories A–D. Category B (an error occurred but did not reach the patient) contained the largest number of errors (64.1%), followed by Category A (an event occurred that had the capacity to cause error) with 18.9% and Category C (an error occurred that reached the patient but did not cause harm) with 13.9% of errors. We identified a total of 338 error reports as potential candidates for test scenarios and narrowed these down by combining similar scenario types (i.e., orders for drug to which patient was allergic) and prioritized based on preselected criteria of (a) frequency, (b) seriousness, and (c) testability. We then attempted to determine the extent to which current CPOE systems were vulnerable to similar errors. These test scenarios described 13 categories of erroneous or problematic orders arising from realistic clinical encounters including: wrong drug, amount, dose, route, units, or frequency errors; omission errors; duplicate drug or therapy; adjacency errors; drug allergies; drug-drug interactions; and drug-disease contraindications (see supplementary online Appendix 1).

**Conducting the tests**

After obtaining the necessary ethical and institutional approvals, testers were instructed to enter these problematic orders on test patients: these were based on CPOE-related errors reported to a leading medication error reporting system. For example, testers were instructed to enter Synthroid (levothyroxine) 100 mg PO daily (instead of 100 mcg PO daily), which represented a 1000-fold overdose (Test Case 9). They were encouraged to enter these orders in the usual and customary way, and where necessary perform workarounds that they might typically use to enter such orders. A research assistant (D.L.W.) accompanied by either a research pharmacist (M.G.A., A.C.S.) or general internist (G.D.S.) independently observed the testers while they attempted to enter these erroneous orders at US sites. Similarly, at the Canadian sites an academic physician (T.E.) observed the testers enter these orders. For each test scenario, the observer rated the ease or difficulty using a specially designed data collection sheet and operational definitions (see Appendices 2 and 3, respectively). Testers were also asked to reflect on the overall process, sharing their knowledge and experience of using their CPOE system. All test sessions were conducted between August 2011 and March 2012.

**RESULTS**

We examined 13 unique CPOE systems across 16 different sites in the United States (n = 11; Sites 1–11) and Canada (n = 5; Sites 12–16). Two different testers entered the orders at each site, apart from Sites 8, 9, and 11 (see Table 1), and we tested two versions of the same system (inpatient and outpatient) at two specific sites (i.e., Sites 6 and 7). Table 1 also includes observers’ rating scores relating to the ease or difficulty in placing the order; no particular setting (in patient vs outpatient) or type of system (commercial vs in-house) appeared substantially better than any other.

**Generation of alert warnings**

We found instances where the same vendor CPOE system responded differently at two different sites for Test Case 1 (allergy-drug checking), with one displaying no warning messages (e.g., Site 8) and the other providing warning messages that required the tester to give a coded reason to override the alert (e.g., Site 2). These different responses may relate to how the information was entered in the system. For example, when the tester entered “allergy to lisinopril” in an unstructured format (free-text), no allergy warning appeared after selecting “captopril 12.5 mg tabs” from the medication list. However, when the tester added the allergy in a structured format (by selecting lisinopril from a medication list), a red warning appeared stating: “captopril 12.5 mg tabs note prior adverse reaction with Lisinopril.” A similar situation arose for Test Case 12 (wrong dose frequency), with no warning messages displayed when the tester entered the dose frequency “QID” (four times each day) in free text for Cardizem CD (diltiazem extended release) 120 mg at one site (e.g., Site 2). However, when the order was placed by changing the dose frequency from “daily” to “QID” (structured format) in the same system at another site (e.g., Site 8), a warning message was displayed stating: “This product is usually given ONCE DAILY” although it could easily be overridden with a single keystroke.

In Test Case 4 (duplicate drug checking), a duplicate drug warning was generated in one system (e.g., Site 1) when the tester entered an order for Lovenox (enoxaparin sodium injection) 40 mg subcutaneous daily followed by a second order for Lovenox 100 mg subcutaneous twice a day. However, no duplicate alert warnings were displayed if the tester drafted both medication orders in succession in electronic scratchpad before signing. Scratch pad (buffer) can hold orders and
were ordered in sequence in Test Case 6 (duplicate therapy checking) at the sulfonyl-urea class. GlipiZIDE, a different oral blood-glucose-lowering drug which belongs to the sulfonyl-urea class. It should not be confused with LASA Intervention- GlyBURIDE is an oral blood-glucose-lowering drug which was being generated for other drugs including glyburide: Case 10 (adjacency error). Yet at one site (e.g., Site 5), LASA warnings were not displayed when metformin and Glucovance were ordered instead of V R (glyburide and metformin combination) (e.g., Sites 6 and 10). For Test Case 3 (drug-disease checking), the tester under- ment” (e.g., Site 9). The tester felt this wording was unclear and dis- liked the way warnings for all active orders appeared on the same screen, including those not relevant to the current erroneous order (for which an alert would be most relevant). Another tester also shared a similar view, explaining how alert warnings (including those generated from previous orders) were listed in the same pop up window in the same type of commercial CPOE system at a different site (e.g., Site 3). The wording of alert warnings differs substantially among the systems tested. Some systems used more specific terms than others, which might help reduce the number of false positives and increase user acceptance. For example, one system used the phrase “already exists” instead of “duplicate” in its warning message. This wording was preferred by testers as it avoided confusion with “duplicate” in other contexts.

Table 1. Characteristics of Data Collection Sites and Scores

<table>
<thead>
<tr>
<th>Site</th>
<th>Site Classification</th>
<th>Inpatient/Outpatient Setting</th>
<th>Number of Beds</th>
<th>CPOE System</th>
<th>Sum of Scores</th>
<th>Average Scores</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Academic medical center</td>
<td>Combination – Inpatient/Outpatient</td>
<td>301–500</td>
<td>Commercial</td>
<td>34</td>
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<tr>
<td>2</td>
<td>Multispecialty group practice</td>
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<td>&gt;500 000 outpatient visits/year</td>
<td>Commercial</td>
<td>34</td>
<td>2.6</td>
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<td>Inpatient</td>
<td>101–300</td>
<td>Commercial</td>
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<td>3.7</td>
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<td>In-house</td>
<td>30</td>
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</tr>
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<td>5</td>
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<td>500 or more</td>
<td>In-house</td>
<td>41</td>
<td>3.2</td>
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<td>6A</td>
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<td>Commercial</td>
<td>29</td>
<td>2.2</td>
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<tr>
<td>6B</td>
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<td>12 000 patients</td>
<td>Commercial</td>
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<td>1.6</td>
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<td>Commercial</td>
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<td>2.7</td>
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a Our agreement with the test sites precludes revealing more specific details about each system.

b The sum and average scores across all 13 tests in answer to the question “How easy was it to place the erroneous order?”

Private practice physician offices did not contain beds hence not applicable (N/A). Sites 6 or 11. According to the respective testers at these sites, “all duplicate order checking is in name only, i.e. there is no ingredient checking” for combination drugs (e.g., Site 11) and “order set capability is geared toward ordering multiple tabs in combination to obtain desired dose” (e.g., Site 6). There may be situations when two drugs from the same class should be prescribed, and thus providing a system warning for individual drug duplicates as opposed to class duplicates would be more appropriate. Finally, we were sobered to find that in one system, all alerts were inadvertently turned off—an unintended consequence of an upgrade to a new release 6 months earlier, only discovered when we undertook our scenario testing of that system.

The wording of alert warnings

Testers often found the wording of alert warnings and ways the information was displayed confusing. In Test Case 4 (duplicate drug checking), the duplicate drug warning never explicitly said “duplicate” but specified how the drug “already exists . . . under the selected assessment” (e.g., Site 9). The tester felt this wording was unclear and disliked the way warnings for all active orders appeared on the same screen, including those not relevant to the current erroneous order (for which an alert would be most relevant). Another tester also shared a similar view, explaining how alert warnings (including those generated from previous orders) were listed in the same pop up window in the same type of commercial CPOE system at a different site (e.g., Site 3).
11). He found himself sifting through all of these warnings in order to find the relevant one(s). Although they could be ordered in terms of severity, this tester felt that the way these warnings were displayed added to the burden of “alert fatigue” at this site.

In Test Case 3 (drug-disease checking), the tester at one site (Site 2) received a best practice advisory warning (as opposed to a drug-disease alert) noting that pioglitazone was contraindicated in patients with CHF. These types of alerts were felt to be common and for “less severe warnings/interactions.” The tester explained how this particular warning—which was arguably more “critical” than most—could easily “get lost in the long list of other warnings that show up simultaneously.” The drug-disease warnings that appeared in another system (e.g., Site 9) were considered “prominent but confusing” to the tester. He reflected on how it was hard to know which of the two warnings (that appeared in quick succession) were “actually more severe,” with one bright red warning stating “Not recommended” and another in orange stating “Extreme Caution.”

The timing of alert warnings

The timing of alert warnings differed across CPOE systems. Testers noted how for Test Case 2, drug-disease interaction warnings were displayed after both Imdur® (isosorbide mononitrate) and Revatio® (sildenafil) had been selected and the order was already signed in two different systems (e.g., Sites 2 and 7). It was relatively easy to get to the signing stage but an override box still “needed to be checked” before the order could be sent to pharmacy (e.g., Site 7). Similarly, in Test Case 6 (duplicity therapy checking), the duplicate therapy warning appeared after both metformin and Glucovance® (glyburide and metformin combination) had been ordered and signed (e.g., Site 1). In contrast, the same duplicate therapy warning appeared before the second order was signed in a different system (e.g., Site 7).

Unfortunately, a number of well-timed warnings were ignored by testers who frequently voiced the dangerous assumption that “the pharmacists would catch” any errors that they missed.

The level of severity of alert warnings

Alert warnings varied in their level of severity in different CPOE systems. For example, in Test Case 2 (drug-drug interaction checking) some systems generated an “Information only” alert when Imdur® (isosorbide mononitrate) and Revatio® (sildenafil) were ordered together (e.g., Site 6). This was in contrast to others, which generated a hard stop “critical alert” [highlighted in red] (e.g., Sites 4 and 5); the latter required the testers to either cancel the current order or discontinue one of the drugs in order to proceed. Similarly, for Test Case 4 (duplicity drug checking), the tester was presented with a hard stop alert warning after entering an order for Lovenox® (enoxaparin sodium injection) 40 mg subcutaneous daily followed by a second order for Lovenox® 100 mg subcutaneous twice a day in the inpatient system (e.g., Site 7). When placing the same order using the equivalent outpatient system at the same site, the tester was presented with an interruptive alert warning that could easily be overridden with a single keystroke. Testers at Sites 3, 5, and 11 commented on how they might often need to prescribe the same drug twice in certain cases—for example, a different dose of a diabetic drug in both the morning and evening, and thus developed workarounds such as entering the brand name of the drug, e.g., Glucotrol® (glipizide) for the morning and the generic name of the drug (glipizide) for the evening dose to avoid getting duplicate drug alert warnings.

CPOE workarounds

Testers overcame certain challenges when entering Test Cases 9, 11, and 13, as the drug name was presented alongside the dose, route, or indication in some CPOE systems respectively; they developed various workarounds which they had previously learned in using the system, such as (i) using the “other” option, (ii) making free text entries in the special instructions or comments field, (iii) changing the default settings, and (iv) selecting “off formulary” drugs. For example, in Test Case 9 (wrong units), testers were presented with the dose alongside the drug name or dosage product (e.g., Synthroid® 100 mcg), which made it difficult to enter the wrong units or dose (mg vs mcg). One tester successfully placed the order for a 1000-fold overdose of Synthroid® (levothyroxine) by selecting the “other” option from the pull down menu, entering “100” in the free text box, and selecting the units “mg” from the dose list (e.g., Site 7). Testers successfully changed the default strength from “100 mcg” to “100 mg” in the same system without any difficulties at two other sites (e.g., Sites 9 and 11). Finally, another tester selected Synthroid® (levothyroxine) from the “off formulary” list as this had no dose attached to it (e.g., Site 6) and then successfully entered “100 mg by mouth daily” in free text in the “instruction” field.

Testers were presented with the route alongside the drug name in some CPOE systems, e.g., Tylenol® (acetaminophen) PO (by mouth) tabs (Site 4), a protection which made it difficult to select the wrong route in Test Case 11 (wrong drug route/directions). However, testers were able to circumvent this critical safety feature and successfully place the erroneous order by making a free text entry in the special instructions or comments field. One tester was able to type over the default value of “take 2 tabs” in their CPOE system (e.g., Site 11) and noted how “1 puff” and “1 spray” were also presented as selectable options for Tylenol® tablets. No relevant warnings were generated in any of the CPOE systems (where the successful orders were placed). Another tester at a different site (Site 3) found it hard to find the right drug form, and so (based on previous experience of using such a workaround) intentionally selected the wrong form from the product list and provide instructions to pharmacy to give a different form.

Finally, in some systems, testers were presented with the indication alongside the drug name, which could help prevent selection of the wrong dose for the intended indication in Test Case 13 (wrong dose for indication; a dangerous not infrequently reported error).19 A maximum weekly dose of methotrexate was associated with each of the drug-indication options in one system (Site 4), including 12.5 mg for Methotrexate (RHEUM) PO, and 15mg for Methotrexate (Non Oncology Use).” Testers performed workarounds by either typing “15 mg” in free text in the dose field and “OD” (every day) in the frequency field for “Methotrexate (RHEUM) PO,” or selecting “QD” from a structured list for “Methotrexate (Non Oncology Use).” No alert warnings were displayed in either case. This erroneous order was able to be readily placed in all CPOE systems except one (Site 5) where the testers were unable to change or select “other” to enter a free text frequency; special authorization was required in this system to prescribe higher doses/greater than weekly frequencies for “chemo” orders.

DISCUSSION AND CONCLUSION

We found an array of CPOE systems often failed to detect and prevent previously documented and potentially dangerous medication errors. The generation of electronic alert warnings varied widely between systems, and depended on how the order information was entered into the system (i.e., in a structured or unstructured way), whether a specific alert functionality (e.g., duplicate-drug checking) was operational in the system, and which drugs or drug combinations were included in the CDS algorithms). The wording of alert warnings was often found to be confusing, with unrelated warnings appearing on the same screen as those more relevant to the current erroneous entry that was made.
The timing of alert warnings differed across CPOE systems, with many dangerous drug-drug interaction warnings displayed only after the order was placed. Alert warnings also varied in their level of severity in different systems and even within the same institution (outpatient vs inpatient system). Testers demonstrated a variety of workarounds which they had discovered (and used in their practice) to enter such erroneous orders such as (i) using the “other” option, (ii) making free text entries in the special instructions or comments field, (iii) changing the default settings, and (iv) selecting “off formulary” drugs. Thus, “free text” represented both a blessing (ability to overcome frustrations in entering desired orders, and communicating intent directly with pharmacy) and curse (circumvented CDS safety checks).

Testing revealed a range of CDS protections that were either switched off or non-existent in the different CPOE systems. For example, none of the systems generated LASA alerts when “penicillamine” was ordered instead of “penicillin.” In contrast, LASA warnings were generated for other drugs at one site. Errors relating to the incorrect selection of adjacent drugs from drop-down menus are increasingly being reported in the literature. The USP identified approximately 1470 unique drugs implicated in medication errors due to brand and/or generic names that looked or sounded alike. It is therefore important that relevant LASA warning capability is operational in CPOE systems and targets at least the most frequent drug pairs previously implicated in medication errors. Also, incorporating the “indication for use” as part of the medication orders could potentially prevent drug name error (e.g., “penicillamine” being ordered for the treatment of rheumatoid arthritis or Wilson’s disease rather than penicillin for bacterial infection).

The wording of alert warnings was found to be unclear in some CPOE systems. Human factors principles always need to be considered when developing and implementing medication-related alerts and the content of these alerts validated for clarity and understandability with the intended users. Display of various warnings completely unrelated to erroneous order (e.g., obscure drug-drug interaction (DDI) warnings) was frequently noted in some CPOE systems and warrants further attention as excessive irrelevant warnings are likely to contribute to alert fatigue with providers overlooking more relevant serious warnings. The need to strike the right balance between useful alerting and over-alerting in CPOE systems has previously been emphasized, with valuable threats to patient safety and help provide solutions as technology is introduced and updated.

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This study has several implications. Despite two decades of development of CPOE systems and CDS, organizations are probably not getting all the safety benefits that they could, given the level of variability we found. We fear this slow progress means both that patient safety is not being protected, and learning and improvement needs to be accelerated. Second, it would not have been possible to anticipate all the sorts of issues that have arisen. Thus, there is a clear role for post-implementation testing using a variety of clinical scenarios that could enable organizations to improve their systems. The net result is that both vendors and hospitals can draw valuable lessons from this kind of evaluation.

This study has several limitations. It was performed at only a small number of institutions, which may not be representative of institutions at large. We also tested a limited number of errant orders, but these were actual issues that had been reported as problematic in the MEDMARX database. By “instructing” testers to enter these erroneous prescriptions, we introduced an element of artificiality: this was unavoidable in a study of this sort. We also do not know how many of these “erroneous orders” would be detected vs overlooked by pharmacists receiving and reviewing these orders. Finally and most importantly, this study did not aim to assess the right balance between under-alerting and over-alerting. We focused on examples of failure to alert, while also documenting evidence of over-alerting from the tester comments we collected. Certainly duplicate warnings for the same drug (e.g., Glucovance® and metformin) are appropriate; alerting on all class duplications (e.g., NSAIDs and aspirin) may not be particularly helpful.

In conclusion, we found a high degree of variability in ordering between different CPOE systems. Major deficiencies were identified in some of these systems and it is therefore critical that developers reflect on these findings and build in safeguards to ensure safer prescribing for patients. Human factor principles should always be considered when introducing medication-related alerts, and the concerns of clinical users who are likely to be directly affected by the decision support capabilities openly discussed. We believe that these findings can assist hospitals in selecting areas for new implementation of decision support or improvement of their current CPOE system.

**ETHICAL APPROVAL**

This study was reviewed and approved by the Partners Human Research Committee, which is the Institutional Review Board of Partners Research Management at Partners HealthCare. (ref #2009-P-002678/1; Brigham and Women’s Hospital (BWH)).
CONTRIBUTORS
G.D.S., A.C.S., and D.W.B. conceived and designed this study, and secured the funding for this work. M.G.A., D.L.W. and T.E. conducted the data collection. S.P.S., M.G.A., T.E., G.D.S., D.W.B. contributed to the analysis and interpretation of data. S.P.S. led the writing of this manuscript with all coauthors commenting on drafts of the paper. All authors gave their approval for the final version to be published. S.P.S. and G.D.S. act as guarantors.

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