Association of Implementation of Practice Standards for Electrocardiographic Monitoring with Nurses' Knowledge, Quality of Care, and Patient Outcomes: Findings from the Practical Use of the Latest Standards of Electrocardiography (PULSE) Trial

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Abstract

Background—Although continuous electrocardiographic (ECG) monitoring is ubiquitous in hospitals, monitoring practices are inconsistent. We evaluated implementation of American Heart Association practice standards for ECG monitoring on nurses' knowledge, quality of care, and patient outcomes.

Methods and Results—The PULSE Trial was a 6-year multi-site randomized clinical trial with crossover that took place in 65 cardiac units in 17 hospitals. We measured outcomes at baseline, Time 2 after Group 1 hospitals received the intervention, and Time 3 after Group 2 hospitals received the intervention. Measurement periods were 15 months apart. The 2-part intervention consisted of an online ECG monitoring education program and strategies to implement and sustain change in practice. Nurses' knowledge (N=3,013 nurses) was measured by a validated 20-item online test, quality of care related to ECG monitoring (N=4,587 patients) by on-site observation, and patient outcomes (mortality, in-hospital myocardial infarction, and not surviving a cardiac arrest) (N=95,884 hospital admissions) by review of administrative, laboratory, and medical record

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data. Nurses' knowledge improved significantly immediately following the intervention in both groups, but was not sustained 15 months later. For most measures of quality of care (accurate electrode placement, accurate rhythm interpretation, appropriate monitoring, and ST-segment monitoring when indicated), the intervention was associated with significant improvement, which was sustained 15 months later. Of the 3 patient outcomes, only in-hospital myocardial infarction declined significantly after the intervention, and was sustained.

Conclusions—Online ECG monitoring education and strategies to change practice can lead to improved nurses' knowledge, quality of care, and patient outcomes.

Keywords

electrocardiography; nursing; outcome assessment (health care); quality of health care; randomized controlled trial

Continuous electrocardiographic (ECG) monitoring is one of the most common technologies used in acute care today. ECG monitoring guides patient care, particularly for patients with or at risk for arrhythmias and myocardial ischemia. In the 60 years since continuous ECG monitoring was introduced,[1] the technology has become more sophisticated and its management more complex. Clinicians need expertise to apply ECG electrodes correctly, interpret waveforms, and respond to the numerous alarms generated by ECG monitoring systems.

Nurses, in particular, have significant responsibility for care of patients receiving ECG monitoring. The nurse is responsible for both technical aspects of monitoring (e.g., electrode placement, alarm parameter settings) and clinical decision-making based on information obtained from the monitor. Nurses must have sufficient knowledge to carry out these responsibilities in ways that maximize quality of care and patient outcomes. However, evidence suggests that nurses lack knowledge and expertise related to ECG monitoring.[2-6]

In 2004, the American Heart Association (AHA) published practice standards to improve hospital ECG monitoring.[7,8] This consensus document was the first attempt to address all aspects of hospital ECG monitoring (arrhythmia, ischemia, and QT interval), including indications for monitoring and practical considerations for correct and effective monitoring. Since publication, the use and value of the AHA practice standards have been assessed in a small number of studies and quality improvement initiatives. Implementation of the AHA practice standards' criteria for ECG monitoring has resulted in decreased use of telemetry monitoring[9,10] and an increased proportion of patients on telemetry monitoring who meet criteria.[10,11] Significant cost savings have been attributed to decreased use of telemetry monitoring associated with implementation of the AHA practice standards.[9,12] Safety of the practice standards related to monitoring the appropriate patients has also been examined.[11-15]

Studies on the implementation of the AHA practice standards have targeted clinicians who order monitoring, by updating the electronic ordering system or providing education on the practice standards' ECG monitoring indication criteria.[9-11] Only one identified study included bedside nurses in the intervention, as part of the ECG monitoring discontinuation

decision process in the electronic ordering system.[9] The significant responsibility nurses have in managing ECG monitoring, however, has not yet been addressed in research evaluating the AHA practice standards.

Studies to date have been useful in determining the value and safety of the AHA practice standards. However, these studies are primarily observational or non-randomized, pre/post intervention assessments, and focused primarily on validating the AHA practice standards' indications for ECG monitoring. To our knowledge, no randomized clinical trials using the AHA practice standards have been published, nor have any studies focused on nurses' roles in implementing the AHA practice standards.

Therefore, the purpose of the Practical Use of the Latest Standards for Electrocardiography (PULSE) Trial was to test the effect of implementing the 2004 AHA practice standards for ECG monitoring on: (1) nurses' knowledge of ECG monitoring; (2) quality of care related to ECG monitoring; and (3) patient outcomes. We hypothesized that our intervention of online education and nursing champions on each unit would increase nurses' knowledge, which would lead to enhanced quality of care, which would result in improved outcomes for patients. The PULSE Trial is an example of translational research, in which the effectiveness of an intervention in real-world clinical practice was tested.

Methods

Design

The PULSE Trial was a 6-year multi-site randomized clinical trial with crossover (Figure 1). We obtained baseline data from all hospitals over a 6-month period at Time (T) 1. We then randomized hospitals to Group 1 (G1) or Group 2 (G2) after stratifying by hospital size based on the number of nurses and number of beds on the participating units. In the crossover design, nurses in G1 hospitals received the 2-part intervention over a 15-month period just after data collection at T1 and nurses in the G2 hospitals received it over a 15-month period right after data collection at T2. The third time point allowed us to offer the intervention to G2 hospitals and measure outcomes, and to assess the sustainability of any improvements in G1 hospitals approximately 15 months later. The time between the T1, T2, and T3 measurements was 15 months. All hospitals received approval from their institutional review boards.

Participants

Nurses and patients in 65 cardiac units in 17 hospitals formed three distinct samples corresponding to the three aims. We included both academic medical centers and community hospitals; 15 hospitals were in the United States, 1 was in Ottawa, Canada, and 1 was in Hong Kong, China. The cardiac units were medical, surgical, or combined units, and included both intensive care units (ICUs) and step-down/telemetry units. We also included non-cardiac-specific units if cardiac patients made up at least 60% of patients treated on these units. Anticipated effect sizes used for sample size calculations were based on surveys of participating hospitals, our preliminary and pilot studies, and relevant research by others.[16,17] We had sufficient power (>80%) to detect group and time differences for nurses'

knowledge and all measures of quality of care. We lacked power for the measures of patient outcomes, e.g., 7% for mortality, but 76% for in-hospital MI.

Nurses' Knowledge—All nurses who worked on the participating units were eligible to participate. Of the 3,013 unique nurses, 686 participated in all three phases of the study. A total of 7,329 ECG monitoring knowledge test scores were obtained. Participation rates varied across hospitals and phase of the study. Mean participation rates ranged from 51.6% for G2 at T2 to 71.2% for G1 at T2. Nurses provided online consent before they accessed the education and testing.

Quality of Care—A total of 4,587 patients cared for on the participating units when the PULSE research nurse was present to collect data were included in the study. The research nurse observed every available patient. Most hospitals did not require written consent from patients.

Patient Outcomes—All patients who were admitted to one of the participating units as their first inpatient unit within the 6-month period that preceded onsite data collection were included in the study. Our sample was all 95,884 admissions to participating units in 13 hospitals over 6 months at each time point. Our sample was reduced from 17 to 13 hospitals because two hospitals withdrew from the study (Figure 2) and two additional hospitals were unable or unwilling to provide patient outcomes data. The 95,884 admissions represented 84,392 unique patients.

Intervention

The 2-part intervention consisted of an interactive online ECG monitoring education program and strategies to implement and sustain change in practice, led by nurse champions on each unit. The Site Investigators designated senior staff nurses on each unit to serve as Unit Champions. The Unit Champions reinforced what the nurses learned in the online ECG monitoring education program, promoted strategies to implement and sustain change in the clinical area, and ensured penetration of the education over all shifts and all days.

For Part 1 of the intervention, three nurses with experience teaching ECG monitoring developed the content of the online education program, which was based on the ECG monitoring practice standards.[7] Several experts in ECG monitoring confirmed content validity before it was converted to an online program. We pilot tested the online program with 124 nurses from six sites in Connecticut and California, and revised it based on their input. The online education consisted of four interactive modules: Essentials of ECG Monitoring, Arrhythmia Monitoring, ST-Segment Ischemia Monitoring, and *QT Interval Monitoring*. Content in the modules was presented using text, images, short videos, interactive simulations, and links to important information. Nurses accessed the online education through a website using individually-assigned usernames and passwords.

Part 2 of the intervention was strategies to implement and sustain change in practice. Four strategies were required for all units:

1. Meetings of Site Investigators and Unit Champions to view and discuss a PowerPoint® program on implementing change in practice

2. Posters and laminated pocket cards emphasizing important points of the online ECG education (e.g., figures of electrode configuration, criteria for ischemia)

3. Monthly conference calls of research team with Site Investigators

4. Presentations of ECG monitoring case studies to nurses

We also encouraged hospital- and unit-specific strategies that Site Investigators and Unit Champions believed would facilitate improved practice at their particular sites.

Outcomes

We evaluated the effect of the intervention on three outcomes: nurses' knowledge, quality of care related to ECG monitoring, and patient outcomes. For the two hospitals that withdrew, we used data we had for nurses' knowledge and quality of care, but did not obtain patient outcomes.

Nurses' Knowledge—Participants took a 20-item online test on essentials of ECG monitoring, and arrhythmia, ischemia, and QT interval monitoring. Prior to the PULSE Trial, we pilot tested a longer version of this test along with the online education program. Based on an item analysis with evaluation of point biserial indices calculated for the whole test and for each item and the Kuder-Richardson reliability coefficient, we revised the test to the version used in the study. Scores represent the percentage of correct answers.

Unit Champions introduced the study to nurses and encouraged their participation. Each nurse was given a unique username and password to log into a dedicated website to take the test and receive the online education. Nurses could participate in the online education and test at work or outside of work hours. Nurses were given a $10 gift card upon completion of the test, and a $40 gift card and continuing education units after completing the online education and posttest.

Quality of Care—Indicators included accuracy of electrode placement, accuracy of rhythm interpretation, cardiac arrest events, appropriate monitoring, and appropriate use of ST-segment and QTc monitoring. One of three specifically trained PULSE research nurses, who were experienced ICU nurses with expertise in ECG monitoring, collected all data during 5-day observation periods at each hospital at each of the three time points. Research nurses observed monitors and electrode placement, and reviewed current medical records for indications for monitoring. They compared arrhythmias stored in the monitor with documentation by unit nurses. Research nurses collected data together once at each time point to check inter-rater reliability. The kappa coefficient was maintained at >.90.

Although we intended that the research nurses would be blind to group assignment of the hospitals, we soon realized that blinding was impossible. Nurses with whom they were in close contact knew if their hospitals were in G1 or G2.

Patient Outcomes—We chose to examine mortality, in-hospital myocardial infarction (MI), and not surviving a cardiac arrest because we believed that they could be influenced by effective continuous ECG monitoring. We obtained administrative data (e.g., discharge diagnosis, ICD-9-CM codes, mortality) and laboratory data (e.g., troponin, CK-MB) for all patients. Mortality was defined as death that occurred on one of the participating units. To identify the occurrence of in-hospital MI, we used laboratory data, timing of procedures, and location of patient at the time of the first blood draw indicating the event (algorithm in Supplement). For survival after cardiac arrest, we first identified all patient visits associated with the ICD-9-CM procedure code for cardiopulmonary resuscitation (99.60) and/or the ICD-9-CM diagnosis code for cardiac arrest (427.5). We then reviewed medical records to obtain further description of each event. We defined a cardiac arrest as an event initiated by an arrhythmia that required immediate intervention, and was initiated on a PULSE participating unit. For each qualifying cardiac arrest we determined whether the patient survived the event.

Statistical Methods

We conducted all analyses using SAS® software v9.3. We used frequencies and measures of central tendency and dispersion to describe the samples for each of the three aims. We examined distributions and frequencies on all demographic and clinical variables, and compared them across the two groups.

To assess the effectiveness of the intervention on nurse's knowledge, we used mixed models taking into account repeated measures within each of the three time periods for each nurse. We also included a random effect for hospital to account for intra-hospital correlation. We included group, time, and an interaction term.

For quality of care, we used multi-level logistic regression treating unit nested in hospital as a random effect. We included group, time, and an interaction term for these analyses, and adjusted for race and primary diagnosis (cardiac or not).

For patient outcomes, we used multi-level logistic regression treating unit nested in hospital as a random effect. The model of in-hospital MI had a small random effect and failed to estimate standard errors of some coefficients, so we ran the logistic model without a random effect. We included group, time, and an interaction term in the model, and adjusted for gender, race, age, and diagnosis (cardiac or not).

For all analyses, we tested specific hypotheses through estimate statements adjusting for multiple comparisons using a Bonferonni correction. To examine intervention effects, we tested for improvement from T1 to T2 in G1 and from T2 to T3 in G2 simultaneously. Additionally, we examined if the improved outcome at T2 was sustained at T3 in G1. For this comparison, we used a one-sided test to reject a null hypothesis of improvement or no change from T2 to T3 in G1 with a 5% type I error.

Results

Figure 2 shows the number of hospitals that were randomly assigned, received the intervention, and whose data we analyzed for each of the three aims (nurses' knowledge, quality of care, and patient outcomes).

Nurses' Knowledge

Sample Characteristics—The mean age of the 3,013 unique nurses was 37.5 years and ages ranged from 19 to 71 years. The sample was 89% female and 76% white; 72% had a bachelor's degree or higher. Almost half perceived their expertise related to ECG monitoring to be average (Table 1).

Knowledge Test Scores—Over the three time points, 7,329 knowledge test scores were obtained from the 3,013 nurses. As predicted, mean test scores improved significantly in each group, from 49.2 and 49.4 to 70.2 and 71.0 immediately after the intervention (Table 2). However, in G1 at T3, 15 months after the intervention, the mean test score gain was not sustained at T3 (59.4). Although this score is significantly lower than immediately post-intervention, it is still significantly better than at baseline (49.2; $p<.0001$).

Quality of Care

Sample Characteristics—The characteristics of the 4,587 patients observed for quality of care indicators are displayed in Table 3. The mean age of this sample of patients was 65.5 years and the sample was 83% white and 57% male. One-third of patients on these cardiac units had a non-cardiac diagnosis on admission. The most common cardiac diagnosis was acute MI or rule out MI.

Significant differences between the two groups for race occurred at T1 ($p <.0001$) and T3 ($p = .0039$): G2 was more likely to have black patients and G1 was more likely to have Asian patients. G1 was significantly more likely to have patients with a non-cardiac diagnosis at all three time points ($p =.0015$, $.0003$, and $.0015$, respectively).

Accuracy of Electrode Placement—A majority of patients (77.4%) had ECG electrodes placed according to the standard Mason-Likar 5-electrode configuration. Table 2 shows the proportion of patients with accurate electrode placement for four electrodes at the three time periods in each group. The right leg electrode is not included because it can be placed anywhere on the body. For the precordial, or V, electrode, we defined correct placement as in any of the six V electrode locations.

Placement of the left leg and V electrodes was significantly improved after the intervention in G1. Placement of all four electrodes was significantly better after the intervention in G2. The intervention effect was sustained in G1 at T3 for all electrodes. At T3, >90% of limb electrodes were placed correctly in both groups, whereas only 62% to 65% of V electrodes were placed correctly. Additional analysis on the possible confounding effect of sex on V electrode placement revealed that when collapsed over all three time points, accuracy of placement for men was 42.6% vs. 43.1% for women ($p=.77$).

Accuracy of Rhythm Interpretation—Table 2 shows findings related to the accuracy of documented rhythm interpretation. The rhythms evaluated were atrial fibrillation or flutter, non-sustained ventricular tachycardia (6 consecutive premature ventricular contractions), asymptomatic sustained ventricular tachycardia, supraventricular tachycardia of questionable etiology, second or third degree atrio-ventricular block (<40 beats per minute), junctional rhythm (<40 beats per minute), pacemaker failure, pauses >2 seconds, and conversion to sinus rhythm.

The accuracy of the documented rhythm interpretation improved significantly from 82% to 97% and 98% after the intervention in both groups. The improvement in G1 was sustained at Time 3.

Cardiac Arrest Events—We also examined cardiac arrest events requiring emergency intervention (N=33) and a subset of these events initiated by an arrhythmia (N=25), such as symptomatic sustained ventricular tachycardia, ventricular fibrillation, torsade de pointes, and asystole/severe bradycardia. The occurrence of these arrhythmias presumably could have been affected by improved ECG monitoring. Because cardiac arrest events occurred with such low frequency in the 5 days that the PULSE research nurse was on site, including no events in G1 at Time 2, meaningful statistical analysis was not possible (Table 2).

Appropriate Monitoring—Table 2 shows the results of our evaluation of the appropriateness of monitoring in non-ICU settings. We examined the percentage of the 4,174 observations of patients on a telemetry monitor who were appropriately monitored according to the AHA practice standards.[7] We found that the proportion of those on a monitor with an indication increased significantly at T2 after the intervention in G1 to 70%, and at T3 after the intervention in G1. The improvement was sustained at T3 15 months later in G1 (70%).

Appropriate Use of ST-Segment and QTc Monitoring—We found that the appropriate use of ST-segment monitoring was significantly better in G2 after the intervention (p=.0176; 44% at T2 to 45% at T3) (Table 2). The improvement in G1 after the intervention was not statistically significant (p=.0608; 56% at T1 to 67% at T2, but was sustained at T3 (p=.2895; 75%). Due to a strong intra-class correlation when treating unit nested in hospital as a random effect (intra-class correlation = 0.62), the estimated proportions are very different from the observed proportions, thus accounting for the presence and absence of statistical significance of the comparisons. The estimated proportions are 23% at T2 and 53% at T3 in G2 and 48% at T1 and 72% at T2 in G1. The improvement in G1 was sustained at T3 (66% at T3).

Evaluation of the QTc is essential for patients receiving drugs that prolong the QTc and are, thus, at risk for the potentially fatal arrhythmia torsade de pointes.[18] For the appropriate monitoring of QTc, we found significant improvement after the intervention in G1, but not in G2 (Table 2). The improvement in G1, however, was not sustained at T3.

Patient Outcomes

Sample Characteristics—Table 4 shows the characteristics of our sample of 84,392 unique patients. Of note is that over half (53.2%) of the patients on the participating cardiac units had a primary discharge diagnosis that was not cardiac.

At all three time points, patients in G1 were significantly (p<.05) more likely to be female, white, and have a non-cardiac diagnosis, compared with patients in G2. At T1, patients in G1 were significantly younger, but age did not differ between the groups at T2 and T3.

Mortality, In-Hospital MI, and Not Surviving a Cardiac Arrest Event—These outcomes occurred infrequently (Table 2). The intervention had no association with mortality or with not surviving a cardiac arrest event. However, the intervention was associated with a decline in the occurrence of a MI during hospitalization. The proportion of patients with an in-hospital MI was significantly lower in both groups after the intervention and the decline was sustained at T3 in G1.

Discussion

In this multi-site randomized clinical trial with crossover, we tested the effect of an online ECG monitoring education program and strategies to implement and sustain change in practice on nurses' knowledge, quality of care, and patient outcomes. Nurses' knowledge improved significantly immediately following the intervention in both groups, but was not sustained 15 months after the intervention in G1. For most measures of quality of care related to ECG monitoring, the intervention was associated with significant improvement, which was sustained for 15 months. For the three patient outcomes examined, only the occurrence of in-hospital MI declined significantly after the intervention, and that reduction was sustained for 15 months.

Intervention

We chose an online instead of a traditional classroom approach primarily because of the flexibility of access and the assurance that all nurses in this multi-site study would receive the same educational intervention. Classroom, online, and a blending of both have all shown improvement in ECG knowledge.[19-23] Unlike previous research that focused on 12-lead ECG and arrhythmia interpretation, we addressed continuous ECG monitoring and included ST-segment and QTc monitoring.

Because knowledge is necessary but not sufficient, we also incorporated strategies to implement and sustain change in practice. Although previous studies examined the application of aspects of ECG monitoring,[2,4,24-26] none included specific strategies to translate continuous ECG monitoring knowledge into practice.

Nurses' Knowledge

Scores on the ECG monitoring knowledge test at baseline were low, with the mean score less than 50 (possible range 0-100), thus confirming the need for this study. Although test

scores improved after the education, gains diminished over time, but were better than at baseline. Others also found a significant decrease in ECG knowledge test scores over time.[19]

Quality of Care

A key element of the strategies to implement and sustain change in practice was the use of expert nurse champions on each unit to ensure long-term improvement despite staff turnover. The purpose of these multifaceted strategies was to change unit culture related to ECG monitoring. We implemented this translation approach to increase the likelihood of sustained change.

Proper placement of monitoring electrodes on the torso is essential. Misplacement off the designated site can alter waveform morphology and lead to misdiagnosis of arrhythmias and ischemia. For all the electrodes, the intervention was associated with improvement in the correct placement, although change for the arm electrodes only approached statistical significance in G1, but the improvement was sustained for 15 months. Of particular interest are the results for the V lead. At baseline, the percentage with the correct placement was low, especially in G1 (20%). Both groups showed significant improvement after the intervention, although there remained room for improvement. Others who evaluated the 5-electrode Mason-Likar system for continuous monitoring, reported similar results, including a low rate of correct V lead placement.[4,27] The interventions in these studies were similar to ours and included education and auditing of electrode placement with real-time feedback by unit champions [4] and tip cards and posters.[27]

Although the primary purpose of continuous ECG monitoring is the rapid detection of arrhythmias, research has shown that arrhythmias are frequently missed.[28] Our intervention was associated with a significant improvement in the accuracy of interpretation of the non-life-threatening rhythms we examined; and the improvement was sustained for 15 months. Life-threatening arrhythmias leading to cardiac arrest were very rare.

The appropriateness of monitoring has received attention recently, primarily due to the recognized need to manage monitor alarms to avoid alarm fatigue and related sentinel events. Perhaps too many patients are being monitored, resulting in excessive false and non-actionable alarms. Eliminating unnecessary monitoring can result in a reduction in alarm burden with a higher proportion of clinically meaningful alarms and faster response times.[9] Although the AHA practice standards specify the indications and duration of monitoring, studies have shown that monitoring is overused.[12,29] We found that appropriate monitoring increased immediately after the intervention and was sustained for 15 months. Because our intervention was directed to nurses, and not physicians or others responsible for ordering monitoring, the reason for this improvement is unclear. Perhaps it was due to a change in unit culture, in which nurses were more likely to question orders for telemetry monitoring for patients who do not have a clear indication.

The AHA practice standards[7] recommend continuous ST-segment monitoring for patients at significant risk for myocardial ischemia that, if sustained, may result in acute MI or extension of a MI. ST-segment monitoring is especially useful for patients who do not perceive or cannot communicate symptoms of ischemia. Our findings related to ST-segment

ischemia monitoring were initially puzzling. The observed increase in the proportion of appropriate monitoring from 56% to 67% after the intervention in G1 was not significant, whereas the increase in G2 from 44% to 45% post-intervention was significant. In an attempt to understand this, we calculated the estimated proportions. Likely reasons for the large difference in observed versus estimated proportions of appropriate ST-segment monitoring are: 1) the contribution of each hospital was different at the three time points, i.e., the sample size in the hospitals varied; and 2) individual hospitals had varying rates of appropriate use of ST-segment monitoring, i.e., strong intra-class correlation. The observations within each unit are highly correlated. If a unit used ST-segment monitoring, they were likely to use it on all appropriate patients, whereas if a unit did not use it, none of the patients would have had ST-segment monitoring, regardless of indication.

A similar phenomenon occurred with QTc monitoring. We learned from the Site Investigators that some units had no protocol for measuring and documenting the QTc, whereas protocols in other units required nurses to measure and document the QT and QTc on all patients, regardless of whether it was indicated. Site Investigators explained that obtaining the QTc was not difficult so it would be easier to document it on all patients, rather than determining if each patient had an indication. Our intervention was not associated with improvement in the appropriate use of QTc monitoring, except immediately after the intervention in G1 when we achieved the highest proportion of appropriate use: only 51%. The low proportion of appropriate documentation of QTc intervals is consistent with baseline findings of Sandau et al.[26] However, their intervention of online education for nurses, electronic notifications when a patient received at least two doses of a QT-prolonging medication, and computerized calculation of the QTc in the electronic health record resulted in significant and sustained improvement in QTc documentation. Our intervention was not as comprehensive nor specific to QTc monitoring.

Patient Outcomes

Improvement in nurses' knowledge and the quality of care that they provide has little value unless it results in better outcomes for patients. Of the three outcomes assessed, only the occurrence of in-hospital MI declined significantly after the intervention, and was sustained for 15 months.

The mechanism of this decline in in-hospital MI could have been related to more appropriate use of continuous ST-segment ischemia monitoring, and subsequent earlier recognition and intervention for ischemia. We found that our intervention was associated with improvement in the appropriate use of ST-segment monitoring, which was sustained 15 months later. The significant and sustained decline in the occurrence of in-hospital MI after the intervention may be related to improved ST-segment monitoring.

In a retrospective, blinded meta-analysis of three multi-site trials of patients with non-ST elevation MI, Akkerhuis et al.[30] found that each transient ischemic event detected by continuous ST-segment monitoring predicted a 25% increase for death/MI at 30 days, after controlling for known baseline predictors for worse outcomes. Bovino et al.,[31] however, did not find an association between ST-segment monitoring and outcomes of predominantly low-risk patients in the emergency department.

It is possible that the intervention was not associated with mortality or not surviving cardiac arrest because occurrences of these outcomes are rare and related to many other factors.

Limitations and Strengths

Limitations of our study include that randomization may not have been completely effective, however, we were able to control for these differences statistically. Second, two hospitals withdrew from the study and two additional hospitals did not allow us access to patient outcomes data. Third, research nurses collecting data could not be blinded to group assignment of the hospitals. Fourth, we found a significant reduction in in-hospital MI after the intervention, as well as a sustained effect, but not for the other patient outcomes. Caution is needed in interpreting these results because we were unable to account for intra-cluster correlation in the model assessing the effect of the intervention on in-hospital MI due to failure of the mixed model to converge. It is possible that the observed significance is a result of not accounting for the intra-cluster correlation.

Strengths of our study include its design and size: an adequately powered randomized clinical trial with crossover. It took place in academic medical centers and community hospitals of varying sizes, thus enhancing its generalizability.

Conclusions

The combination of online ECG monitoring education and strategies to implement and sustain change in practice was effective. Nurses' knowledge, most measures of quality of care (accurate electrode placement, accurate rhythm interpretation, appropriate monitoring, and ST-segment monitoring when indicated), and the outcome of in-hospital MI improved significantly following the intervention. The improvement in nurses' knowledge was not sustained 15 months after the intervention. However, the improvements in quality of care and occurrence of in-hospital MI were sustained, which was likely due to a change in unit culture. This trial contributes to the current body of knowledge by demonstrating that integrating the AHA practice standards[7] into nurses' education and care improves quality of care and patient outcomes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

Appendix

PULSE Site Investigators

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What is Known

- Implementation of the 2004 AHA practice standards' criteria for ECG monitoring has resulted in decreased use of telemetry monitoring, an increased proportion of patients on telemetry monitoring who meet criteria and significant cost savings attributed to the decreased use of telemetry monitoring.

- Observational and pre-/post-intervention studies have determined the value and safety of the American Heart Association (AHA) practice standards for electrocardiographic monitoring.

What the Study Adds

- The multisite randomized controlled PULSE Trial tested the effect of an online educational intervention and nursing unit champions to support the implementation of the 2004 AHA practice standards for ECG monitoring on: (1) nurses' knowledge of ECG monitoring; (2) quality of care related to ECG monitoring; and (3) patient outcomes.

- Integrating the AHA practice standards into nurses' education significantly improved the quality of care related to electrocardiographic monitoring and was associated with a decrease in the occurrence of in-hospital myocardial infarction.

- Although improvement in nurses' knowledge was not sustained 15 months after the intervention, the improvements in quality of care and occurrence of in-hospital MI were sustained, which was likely due to a change in unit culture.
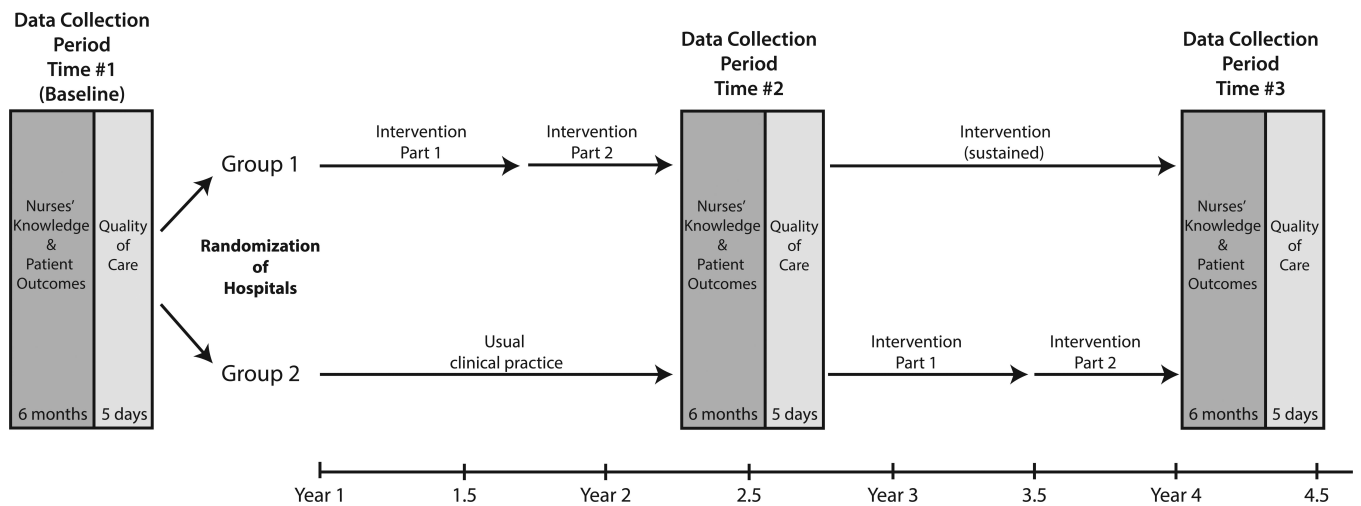
Figure 1. Study design: randomized clinical trial with crossover
At three time points, we obtained measures of our three outcomes: nurses' knowledge (6 months), quality of care (5 days), and patient outcomes (6 months). Following baseline data collection, hospitals were randomized to receive the intervention (Group 1) or to continue their usual practice (Group 2). The intervention consisted of an online ECG monitoring education program (Part 1; 9 months) and strategies to implement and sustain change in practice (Part 2; 6 months). Data were collected from both groups at Time 2 after Group 1 received the intervention. Final data collection occurred at Time 3 after Group 2 received the intervention. Data collection time points were 15 months apart.

Figure 2.
CONSORT flow diagram: hospitals randomized.

Table 1

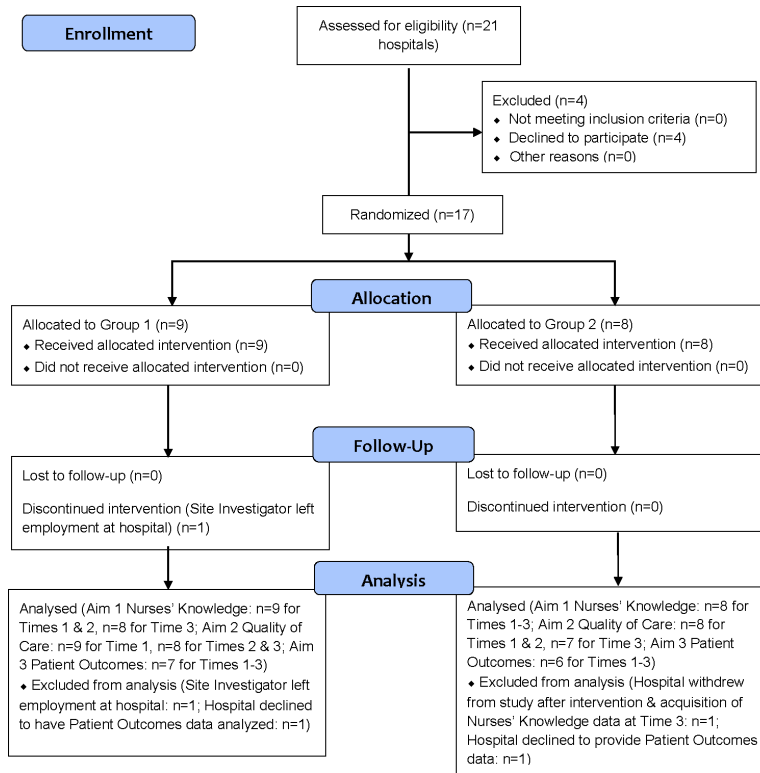Characteristics of nurse participants (N = 3,013 unique nurses)

Characteristic		N	%
Gender			
	Female	2,691	89.3%
	Male	322	10.7%
Race/Ethnicity			
	White	2,278	75.6%
	Asian	469	15.6%
	Black	121	4.0%
	Hispanic	81	2.7%
	Other/Mixed	64	2.1%
Education			
	Diploma	291	9.7%
	Associate's Degree	534	17.7%
	Bachelor's Degree	1,959	65.0%
	Master's Degree	208	6.9%
	Doctoral Degree	11	0.4%
	None of above	10	0.3%
Type of Unit			
	Medicine	1,329	44.1%
	Surgery	830	27.6%
	Combined	854	28.3%
Acuity of Unit			
	Intensive Care Unit	1,385	46.0%
	Non-Intensive Care Unit	1,628	54.0%
Self-Perceived Expertise (N = 1,274 – Asked at Times 2 & 3 Only)			
	Beginner / Need to ask for help	212	16.6%
	Average knowledge	619	48.6%
	Above average knowledge	364	28.6%
	Clinical expert / Resource person	79	6.2%

Characteristic	Mean±SD	Median	Range
Age in Years	37.53±11.05	36.00	19–71
Years Worked as a Nurse	11.51±10.76	8.00	<1–47
Years Worked on a Cardiac Unit	8.06±8.44	5.00	<1–42

Table 2

Intervention and sustained effects on nurses' knowledge, quality of care, and patient outcomes.

Outcome	Time 1		Time 2		Time 3		Intervention Effects*		Sustained Intervention Effect†
	G2	G1	G2	G1	G2	G1	Time 1 to Time 2 in G1	Time 2 to Time 3 in G2	Time 2 to Time 3 in G1
1. Nurses' Knowledge (N = 7,329 test scores from 3,013 unique nurses)									
Mean Test Scores	47.2	49.2	49.4	70.2	71.0	59.4	.0002	.0002	<.0001
2. Quality of Care (N = 4,587 patients)									
Accurate Electrode Placement									
Right arm	83%	87%	82%	90%	91%	94%	.1185	.0002	.9884
Left arm	76%	85%	80%	89%	90%	97%	.0880	.0002	.9463
Left leg	71%	75%	81%	89%	93%	92%	.0002	.0002	.9499
V lead	28%	20%	38%	59%	62%	65%	.0002	.0002	.9508
Accurate Rhythm Interpretation	95%	82%	82%	97%	98%	94%	.0114	.0168	.1350
Cardiac Arrest Events									
Cardiac Arrest	0.56%	1.20%	1.29%	0%	0.32%	0.72%	--	--	--
Initiated by Arrhythmia	0.45%	1.09%	1.16%	0%	0.16%	0.14%	--	--	--
Appropriate Monitoring – Telemetry Units Only	68%	66%	59%	70%	72%	70%	.0002	.0002	.5184
ST-segment Monitoring when Indicated	26%	56%	44%	67%	45%	75%	.0608	.0176	.7105
QTc Measurement when Indicated	28%	13%	34%	51%	35%	45%	.0002	.9999	.0034
3. Patient Outcomes (N = 95,884 admissions of 84,392 patients)									
Mortality – limited to patients discharged from PULSE unit: N = 65,699	2.8%	2.7%	1.9%	2.7%	2.4%	3.1%	.6684	.1602	.0626
In-Hospital MI	3.1%	2.4%	2.9%	1.9%	2.3%	1.5%	.0136	.0160	.9993
Not Survive Cardiac Arrest Event (N = 218)	47.9%	21.1%	32.0%	22.7%	22.6%	25.0%	.9999	.8440	.4230

G1, indicates Group 1; G2, Group 2; MI, myocardial infarction.

*
Adjusted p-values for Bonferroni correction in two simultaneous tests to reject a null hypothesis of no change (two-sided test)

†
p-values to reject a null hypothesis of no change or improved (one-sided test)

Table 3

Characteristics of patients observed for measures of quality of care related to ECG monitoring (N = 4,587 patients)

Characteristic		N	%
Gender (N = 4,579)			
	Male	2,625	57.3%
	Female	1,954	42.7%
Race (N = 4,477)			
	White	3,694	82.5%
	Black	546	12.2%
	Asian	200	4.5%
	Other/Mixed	37	0.8%
Ethnicity (N = 4,475)			
	Hispanic or Latino	226	5.1%
	Not Hispanic or Latino	4,249	94.9%
Primary Admission Diagnosis (N = 4,582)			
	Non-cardiac	1,531	33.4%
	Acute MI or rule out MI	687	15.0%
	Heart failure	672	14.7%
	Arrhythmia or syncope	661	14.4%
	Other cardiac	1,031	22.5%

Characteristic	Mean±SD	Median	Range
Age in Years (N = 4,576)	65.54±5.28	67.00	1-103

MI indicates myocardial infarction.

Table 4

Characteristics of patients evaluated for mortality, in-hospital myocardial infarction, and not surviving a cardiac arrest event (N = 84,392 patients)

Characteristic	N	%
Gender (N = 84,388)		
Male	44,906	53.2%
Female	39,482	46.8%
Race (N = 77,494)		
White	63,093	81.4%
Black	10,758	13.9%
Asian	3,157	4.1%
Other/Mixed	486	0.6%
Ethnicity (N = 51,286)		
Hispanic	5,174	10.1%
Not Hispanic	46,112	89.9%
Primary Discharge Diagnosis (N = 84,308)		
Non-cardiac	44,884	53.2%
Arrhythmia or syncope	9,263	11.0%
Coronary artery disease admitted for PCI or CABG surgery	8,049	9.5%
Acute MI or rule out MI	6,623	7.9%
Heart failure	5,425	6.4%
Other cardiac	10,064	11.9%

Characteristic	Mean±SD	Median	Range
Age in Years (N = 84,343)	64.61±16.34	65.96	9–107

CABG indicates coronary artery bypass graft; MI, myocardial infarction; PCI, percutaneous coronary intervention.