Journal of Cardiovascular Nursing
Vol. 00, No. 00, pp. 00–00 | Copyright © 2023 Wolters Kluwer Health, Inc. All rights reserved.

Agreement of Computerized QT and QTc Interval Measurements Between Both Bedside and Expert Nurses Using Electronic Calipers

Karolina Ho, MS, RN, CNS, CCRN-CSC; Gopika K. Ganesh, MS, RN, CNS; Shelvin Prasad, MSN, RN, CNL; Thomas J. Hoffmann, PhD; Amy Larsen, MS, RN, CNS; Cass Sandoval, MS, RN, CCNS; Sarah Berger, MS, RN, CNS; Hildy Schell-Chaple, PhD, RN, CCNS, FAAN; Fabio Badilini, PhD; Lynda A. Mackin, PhD, RN, AG PCNP-BC, CCNS, GS-C; Michele M. Pelter, PhD, RN, FAHA

Background: In hospitalized patients, QT/QTc (heart rate corrected) prolongation on the electrocardiogram (ECG) increases the risk of torsade de pointes. Manual measurements are time-consuming and often inaccurate. Some bedside monitors automatically and continuously measure QT/QTc; however, the agreement between computerized versus nurse-measured values has not been evaluated. **Objective:** The aim of this study was to examine the agreement between computerized QT/QTc and bedside and expert nurses who used electronic calipers. **Methods:** This was a prospective observational study in 3 intensive care units. Up to 2 QT/QTc measurements (milliseconds) per patient were collected. Bland-Altman test was used to analyze measurement agreement. **Results:** A total of 54 QT/QTc measurements from 34 patients admitted to the ICU were included. The mean difference (bias) for QT comparisons was as follows: computerized versus expert nurses, −11.04 ± 4.45 milliseconds (95% confidence interval [CI], −2.3 to −19.8; *P* = .016), and computerized versus bedside nurses, −13.72 ± 6.70 (95% CI, −0.70 to −26.8; *P* = .044). The mean bias for QTc comparisons was as follows: computerized versus expert nurses, −12.46 ± 5.80 (95% CI, −1.1 to −23.8; *P* = .035), and computerized versus bedside nurses, −18.49 ± 7.90 (95% CI, −3.0 to −33.9; *P* = .022). **Conclusion:** Computerized QT/QTc measurements calculated by bedside monitor software and measurements performed by nurses were in close agreement; statistically significant differences were found, but differences were less than 20 milliseconds (on-half of a small box), indicating no clinical significance. Computerized measurements may be a suitable alternative to nurse-measured QT/QTc. This could reduce inaccuracies and nurse burden while increasing adherence to practice recommendations. Further research comparing computerized QT/QTc from bedside monitoring to standard 12-lead electrocardiogram in a larger sample, including non-ICU patients, is needed.

KEY WORDS: computerized versus nurses, ECG monitoring, electronic calipers, intensive care unit, QT, QTc

Karolina Ho, MS, RN, CNS, CCRN-CSC
Clinical Nurse, UCSF Health, University of California, San Francisco.

Gopika K. Ganesh, MS, RN, CNS
Clinical Nurse Specialist, Kaiser Permanente, San Rafael, California.

Shelvin Prasad, MSN, RN, CNL
Clinical Nurse, UCSF Health, University of California, San Francisco.

Thomas J. Hoffmann, PhD
Associate Professor, Epidemiology and Biostatistics, School of Medicine and Office of Research, School of Nursing, University of California San Francisco.

Amy Larsen, MS, RN, CNS
Clinical Nurse Specialist, Adult Critical Care, UCSF Health, University of California, San Francisco.

Cass Sandoval, MS, RN, CCNS
Clinical Nurse Specialist, Adult Critical Care, UCSF Health, University of California, San Francisco.

Sarah Berger, MS, RN, CNS
Clinical Nurse Specialist, Adult Critical Care, UCSF Health, University of California, San Francisco.

Hildy Schell-Chaple, PhD, RN, CCNS, FAAN
Director of Clinical Practice and Research, Center for Nursing Excellence & Innovation, UCSF Health, University of California, San Francisco.

Fabio Badilini, PhD
Professor, Director, Center for Physiologic Research, Professor Department of Physiologic Nursing, University of California San Francisco.

Lynda A. Mackin, PhD, RN, AG PCNP-BC, CCNS, GS-C
Clinical Professor, Department of Physiological Nursing, School of Nursing, University of California, San Francisco.

Michele M. Pelter, PhD, RN, FAHA
Associate Professor and Director, ECG Monitoring Research Lab, Department of Physiological Nursing, School of Nursing, University of California, San Francisco.

Funding: University of California San Francisco, School of Nursing Clinical Nurse Research Grant, supported by UCSF Health.

The authors have no conflicts of interest to disclose.

Correspondence
Karolina Ho, RN, MS, UCSF Health, 505 Parnassus Ave, San Francisco, CA 94143 (karolina.jedrzejewska@ucsf.edu).

DOI: 10.1097/JCN.0000000000001048

In patients who are hospitalized, QT and QTc (corrected for heart rate) interval prolongation measured on an electrocardiogram (ECG) increases the risk of torsade de pointes, a polymorphic ventricular tachycardia associated with abnormal repolarization of cardiac cells. Given that torsade de pointes can deteriorate into ventricular fibrillation and even death, early identification of QT/QTc prolongation followed by clinical intervention(s) if indicated (eg, magnesium and discontinuation of QT prolonging medications) can avert this potentially lethal arrhythmia.[1] One study found a 24% prevalence rate of QT prolongation, defined as >500 milliseconds for >15 minutes, among 1039 consecutive patients admitted to the intensive care unit (ICU).[2] Furthermore, patients with QT/QTc prolongation had a longer length of hospitalization (276 vs 132 hours, $P < .0005$) and higher risk of mortality (odds ratio, 2.99; 95% confidence interval, 1.1–8.1) as compared with patients without QT prolongation.[2]

The most recently published practice standards for in-hospital ECG monitoring define QT/QTc interval monitoring as high priority in at-risk patients and recommend that hospitals establish uniform protocols for QT/QTc monitoring.[1,3] Although there are known demographic and clinical characteristics that place patients "at risk" (eg, heart disease, older age, female sex, impaired renal and/or hepatic function, QT/QTc prolonging medications, polypharmacy, electrolyte imbalance, and a combination of these factors), it is standard practice to measure the QT/QTc in *all hospitalized patients* with ECG monitoring.[1,2,4] Therefore, nurses must be skilled at measuring QT/QTc and identifying at-risk patients.

Although assessment of QT/QTc interval prolongation is standard practice, multiple measurement challenges have been identified. For example, ECG waveform abnormalities and rhythm disturbances (eg, notched, biphasic, or nonexistent T-waves; artifact; atrial flutter/fibrillation; bundle branch block; pacing; and beat-to-beat variation in the T-wave) make it difficult to measure the QT/QTc accurately.[5] This likely explains why fewer than 50% of nurses accurately measured the QT interval, and only 6% were able to correctly calculate the QTc.[6] These same findings are seen among physicians. In a study of 877 physicians from 12 countries, only 36% of cardiologists and 31% of noncardiologists identified a prolonged QT in patients with long QT syndrome.[7] Training may also be a factor associated with measurement errors. Pickham et al[6] found that accurate QT/QTc measurements significantly improved among nurses after an educational intervention.

The standard practice in most hospital ICUs is to manually measure the QT/QTc using hand-held calipers. However, as stated above, challenges with identifying QT onset/offset and calculating the QTc add to the complexity of manual measurements.[5,8–10] Given these measurement challenges, some bedside monitoring manufacturers now include computerized QT/QTc software that automatically and continuously measures the QT and automatically calculates the QTc.[1,4,11,12] In addition, this software also includes an electronic caliper (e-caliper) feature, which allows nurses to identify the onset and offset of the QT interval, and then it automatically calculates the QTc, which are saved in the bedside monitor. Computerized QT/QTc monitoring software has several advantages. First, the need for manual measurements and additional equipment (eg, hand-held calipers, calculator) is eliminated. Second, the bedside monitor visually displays continuous QT/QTc values derived from multiple ECG leads, allowing clinicians to view values at any given moment. Finally, computerized QT/QTc software includes an alarm feature for QT/QTc changes (eg, >500 milliseconds, or a change ["delta"] from an established baseline), with the goal of alerting busy clinicians to dynamic and/or new changes. However, some hospitals have been hesitant to activate these types of alarms because of the possibility of enhancing alarm fatigue.[13–15] Furthermore, there are some concerns about the accuracy of computerized QT/QTc measurements versus nurse-measured data, either manually or with e-calipers. Therefore, in this study, we aimed to evaluate the agreement between computerized QT/QTc measurements versus bedside and ECG-expert nurses. The rational for including expert nurse comparisons was based on previous research showing that bedside nurse–measured QT/QTc can be inaccurate.[6] In this study, both bedside and expert nurses used e-calipers.

Methods

Study Design

This was a prospective observational study conducted at a 600-bed academic medical center. The following adult ICUs were included: cardiac (14 beds), medical/surgical (16 beds), and neurological (16 beds). The institutional review board approved the study with a waiver of patient consent because protected health information was not collected and we did not collect information from the nurses (IRB# 21-34690).

Sample

The unit of analysis for this study was QT/QTc measurements generated from the bedside monitor (computerized), bedside nurses, and 4 ECG-expert nurses. We collected patient age, sex, and ICU unit type to characterize the sample. Our research team collected data on 2 different days, separated by a 2-week period, to minimize repeat patients and nurses. The ICU standard of care at the time of the study was to measure and document ECG intervals (eg, PR, QRS, RR, and

QT/QTc) at the start of each shift (7 AM and 7 PM) or as clinically indicated (eg, arrhythmia, new/change of QT-prolonging medication(s), and provider order). Up to 2 measurements per patient were obtained, 1 by the morning shift nurse (7 AM) and 1 by the night shift nurse (7 PM) from the previous evening. Thus, for each patient, 2 different nurses measured their QT/QTc. These measurements provided further insight into adherence with QT/QTc monitoring practices.

QT/QTc Measurements

Computerized Measurements

The bedside ECG monitor in use during the study had QT/QTc software installed (Philips Healthcare, IntelliVue MX800, Cambridge, Massachusetts). The QT/QTc software was configured in the bedside monitor as "on"; thus, values were displayed on the bedside monitor and automatically saved. However, QT/QTc alarms were not activated. The software updates the QT/QTc at 1-minute time intervals. Although the bedside monitor utilizes a 5-lead ECG placement, which includes leads I, II, III, aVR, aVL, aVF, and a V lead (default V1), the software only calculates QT/QTc in leads I, II, III, and the V lead, generating a "global" QT/QTc measurement.[12,16] Every 15 seconds, the algorithm performs a QT analysis to determine the average heart rate to calculate the QTc using the Bazett formula (QTc = QT interval in seconds / √RR interval in seconds).[1,17] When the QT/QTc cannot be reliably analyzed by the software (eg, atrial fibrillation, flat T-waves, artifact, small R-waves, and QT out of range [<200 or >800 milliseconds]), an inoperative message alert occurs, and neither the QT nor QTc is calculated.[18]

Bedside Nurse Measurements

The hospital's ICU standard of care includes nurse-measured QT/QTc intervals at the start of each shift (0700 and 1900) using e-calipers available at the central monitoring station. Figure 1 illustrates the e-caliper method used by the bedside nurses. To obtain QT/QTc measurements, ECG leads II and V1, which are the default leads, are typically used. However, an alternative ECG lead can be selected by the nurse if the onset and offset of the Q- and T-wave are difficult to determine in the default leads. The preceding R-R interval is then identified and saved to automatically calculate the QTc. As with the computerized method, the Bazett formula is used. Of note, we did not collect data from the nurses (ie, years of experience, previous education, etc). We also did not account for a nurse caring for 2 patients on the day of data collection, or determine if the same nurse was included on both day 1 and day 2 of data collection, rather the QT/QTc measurements were the unit of analysis.

Expert Nurse Measurements

Four nurses with advanced ECG training and experience performed the QT/QTc measurements using the same steps as the bedside nurses, also using e-calipers (Figure 1). One of the expert nurses is a PhD-prepared nurse scientist with ECG expertise and the other three were ICU nurses, all master's prepared, currently working in 1 of the 3 ICUs included in the study. Two of the ICU nurses had completed a graduate-level ECG interpretation course taught by the PhD-prepared nurse scientist. The expert nurses measured the QT/QTc from an ECG at the same date and time as the bedside nurse. The expert nurses collaborated when measuring the QT/QTc, whereas the bedside nurse performed the measurement by themselves as per the hospital's standard practice. The expert nurses performed the measurement

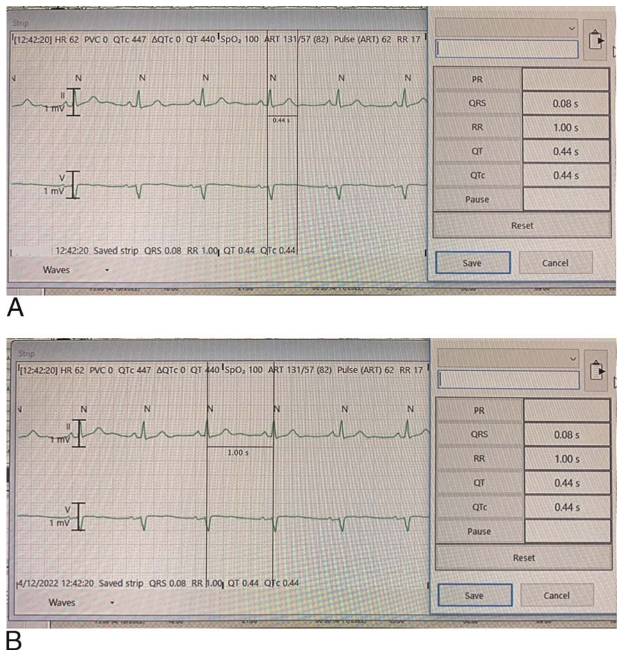

FIGURE 1. *Illustration of the electronic caliper software used for measuring QT/QTc from bedside electrocardiographic monitor. The top image (A) shows how to measure the QT interval (black lines). The nurse positions the left caliper at the onset of the QRS complex and then the right caliper at the end of the T-wave. Once these locations are determined, the nurse clicks the QT button to save the value, which in this example is 0.44 seconds, or 440 milliseconds. The next step is to calculate the QTc to correct for heart rate, using the R-R interval preceding the measured QT interval, which is shown in image B. In this example, the nurse calculated the R-R interval as 1.00 second, or 1000 milliseconds. Once measured, the nurse clicks on the RR button to save the value. Subsequently, the nurse clicks on the QTc button to automatically calculate the QTc value and then selects "save" to store all of the values in the bedside monitor along with the date and time stamp (located at the bottom of both tracings). Note that the saved nurse-measured values (bottom of image) are calculated in seconds, whereas the computerized values (top of tracing) are in milliseconds, which is how this particular vendor displays these values. Note: N = normal QRS complex/beat.*

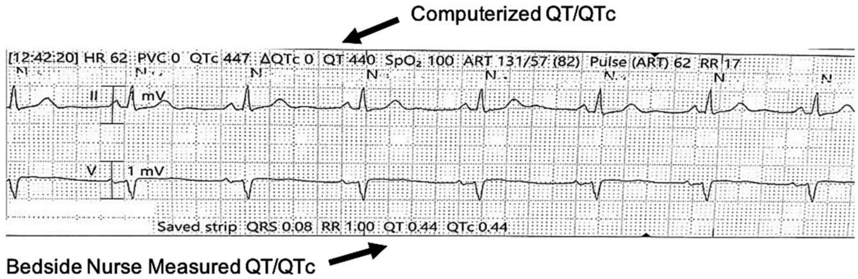

FIGURE 2. *Rhythm strip in leads II and V1 printed from the bedside electrocardiographic (ECG) monitor with QT/QTc measurements made by the bedside nurse (bottom; in seconds) and computerized values (top; in milliseconds). Both values are automatically saved to the bedside monitor. Note that the different QT/QTc values (milliseconds and seconds) are how this particular vendor displays these values.*

in the ICU at the central monitoring station, which is the same procedure used by the bedside nurses.

Comparisons Between Computerized, Bedside and Expert Nurses

The date and time of the bedside nurse-measured QT/QTc were used to identify the ECG to use for comparisons for both the computerized and expert nurse measurements. Figure 2 illustrates how comparisons were made.

Statistical Analysis

Statistical analyses were performed using SPSS (version 27, IBM Corporation, Armonk, New York). The primary analysis compared computerized QT/QTc intervals, which we report in milliseconds, with those measured by the bedside and expert nurses. Scatterplots were generated to evaluate the relationship between the measurement methods. In addition, a Bland-Altman analysis was used to evaluate the agreement between the measurement methods.[19] This approach plotted the mean differences for QT/QTc between the 2 methods against the average of the 2 measurements. A mean difference of 0 or close to 0 indicates strong agreement. Unlike scatterplots, the Bland-Altman test can uncover measurement bias if 1 of the 2 methods is systematically inaccurate at capturing values at either end of the range of values for QT/QTc measurements.

The Bland-Altman analysis identifies the estimated difference between the 2 measurements with 95% limits of agreement around the estimate (mean difference of ±1.96 SD) and was conducted in R v4.0.0 using the BlandAltmanLeh package v0.3.1.[19–21] The mean difference and confidence intervals were determined by a linear mixed model using lme4 v1.1.27.1, to properly account for duplicates (each patient had up to 2 QT/QTc measurements).[22] P values <.05 were considered statistically significant.

Results

This study included 54 QT/QTc measurements collected from 34 ICU patients; hence, 10 (29%) patients had only 1 QT/QTc measurement available for comparison (eg, 7 AM or 7 PM nurse had not performed the measurement). Of the 34 patients included, 53% (n = 18) were male and 47% (n = 16) were female. The mean age was 62 years (±16 years), and the ICU type that the patient was being treated in included cardiac, 35% (n = 13); medical-surgical, 24% (n = 7); and neurological, 41% (n = 14). The expert nurses used the exact ECG (date/time) that the bedside nurse used. However, in 2 instances, the computerized measurements had not been calculated at the exact time of the nurse-measured QT/QTc (both bedside and experts). In these 2 cases, it was not entirely clear why the computerized measurements had not been calculated, but there was a slight artifact seen and was the likely source. Overall, the mean time difference between nurse measurements (both expert and bedside) and the computerized values was 1 minute 19 seconds (±12 minutes 55 seconds). In 1 patient, the time differential was 1 hour 45 minutes. In this patient, the QT and QTc measurements were in close agreement despite the time differential (QT: 368 milliseconds for computerized vs 370 milliseconds for bedside nurses vs 380 milliseconds for experts; QTc: 441 milliseconds for computerized vs 440 milliseconds bedside nurses vs 450 milliseconds for experts). Table 1 shows the mean QT/QTc values for the entire sample.

QT and QTc Measurement Comparisons

The results of the Bland-Altman analysis are presented in Table 2. Scatterplots and Bland-Altman plots for the QT measurements are shown in Figure 3, and QTc measurements in Figure 4. As previously mentioned, QT/QTc values are reported in milliseconds.

Computerized Versus Expert Nurses

As shown in Table 2 and Figure 3A, the QT measurement comparisons between computerized and expert nurses showed a significant mean ± SD bias difference of −11.04 ± 4.45 (95% confidence interval, −2.3 to −19.8, P = .016) and limit of agreement of −75.2 to 53.2 (Table 2, Figure 3A). There was also a significant mean bias difference for QTc, −12.46 ± 5.80 (95%

TABLE 1 Mean QT/QTc Measurements in 34 Intensive Care Unit Patients With 54 QT/QTc Measurements by Method Used

	QT/QTc Measurement, Mean (± SD), ms		
Measurement	**Computerized**	**Bedside Nurses**	**Expert Nurses**
QT	384.15 ± 56.69	370.35 ± 67.53	396.76 ± 59.04
QTc	452.91 ± 49.02	435.67 ± 55.39	467.03 ± 43.89

A statistical test could not be applied here because some patients had 1 QT/QTc value whereas others had up to 2; hence, the assumption of independence was violated. Rather the test for statistical differences was done using a Bland-Altman analysis and is shown in Table 2.

confidence interval, −1.1 to −23.8, *P* = .035) and limit of agreement of −97 to 72 (Table 2, Figure 4A).

Computerized Versus Bedside Nurses

The QT measurement comparisons between computerized and bedside nurses showed a significant mean bias difference of −13.72 ± 6.70 (95% confidence interval, −0.7 to −26.8, *P* = .044) and limit of agreement of −109 to 81.5 (Table 2, Figure 3B). There was also a significant mean bias difference for QTc, −18.49 ± 7.90 (95% confidence interval, −3.0 to −33.9, *P* = .022) and limit of agreement of −136.3 to 99.3 (Table 2, Figure 4B).

Discussion

To our knowledge, this is the first study that has compared computerized QT/QTc measurements from bedside ICU monitors to measurements made by bedside and expert nurses using e-calipers. Our overall results showed that there were statistically significant mean bias differences for both QT and QTc for all comparisons. However, these differences do not seem to be clinically significant, as the largest mean bias difference was 18.49 milliseconds, or one-half of a small box on the ECG paper grid, seen for the QTc comparisons for computerized versus bedside registered nurses. Nevertheless, even this small millisecond difference could be clinically important, particularly in high-risk patients (eg, heart disease, older age, female sex, impaired renal and/or hepatic function, QT/QTc prolonging medications, polypharmacy, electrolyte imbalance, and a combination of these factors), whose QT/QTc is close to 500 milliseconds, which is clinically significant. Therefore, QT/QTc's close to the 500 milliseconds cut point should be carefully examined by nurses to ensure an accurate measurement is obtained and/or confirmed with a standard 12-lead ECG.

In our study, the expert nurses consistently measured a longer QT/QTc than computerized measurements. Computerized measurements were consistently longer than bedside nurse measurements (Table 1). Although one might argue that the observed differences in our study may have occurred because the exact time used for computerized measurement comparisons could vary, all but 1 case had measurements less than 3 minutes apart. Because the QT/QTc interval is not likely to vary substantially during such a short time window, this as a factor can probably be ruled out. Rather, the longer QT/QTc measurements made by the expert nurses may have been because of their advanced training and the fact that they collaborated on the measurements. For example, in a previous study among physicians, QT error rates were the lowest among physicians considered "QT experts," followed by arrhythmia experts, then cardiologists, and finally noncardiologists, respectively.[7] This same trend, but with even higher error rates, was seen for QTc measurements, which the authors attribute to the inability to correctly perform the QTc calculation. In their study, the QT/QTc measurements and calculations (QTc) were done by hand, whereas in our study, e-calipers and automatic QTc software were used to correct for heart rate. We found that the bedside nurse measurements were in close agreement to both the expert nurses and the computerized values, which could be attributed to the following: (1) the use of e-calipers, which might be easier than hand-held calipers; (2) the ability to

TABLE 2 Bland-Altman Analysis of QT and QTc Measurement Comparisons

Comparison Group	Bias, Mean (SD)	95% CI	95% LOA (Lower, Upper)	*P*
QT				
Computerized vs expert RNs	−11.04 (4.45)	−2.3 to −19.8	−75.2, 53.2	.016
Computerized vs bedside RNs	−13.72 (6.66)	−0.7 to −26.8	−109, 81.5	.044
QTc				
Computerized vs expert RNs	−12.46 (5.80)	−1.1 to −23.8	−97, 72.1	.035
Computerized vs bedside RNs	−18.49 (7.90)	−3.0 to −33.9	−136.3, 99.3	.022

Values shown are in milliseconds. The *P* value reports the test of the mean bias using a linear mixed model.
Abbreviations: CI, confidence interval; LOA, limit of agreement; RNs, registered nurses; QTc, QT heart rate corrected.

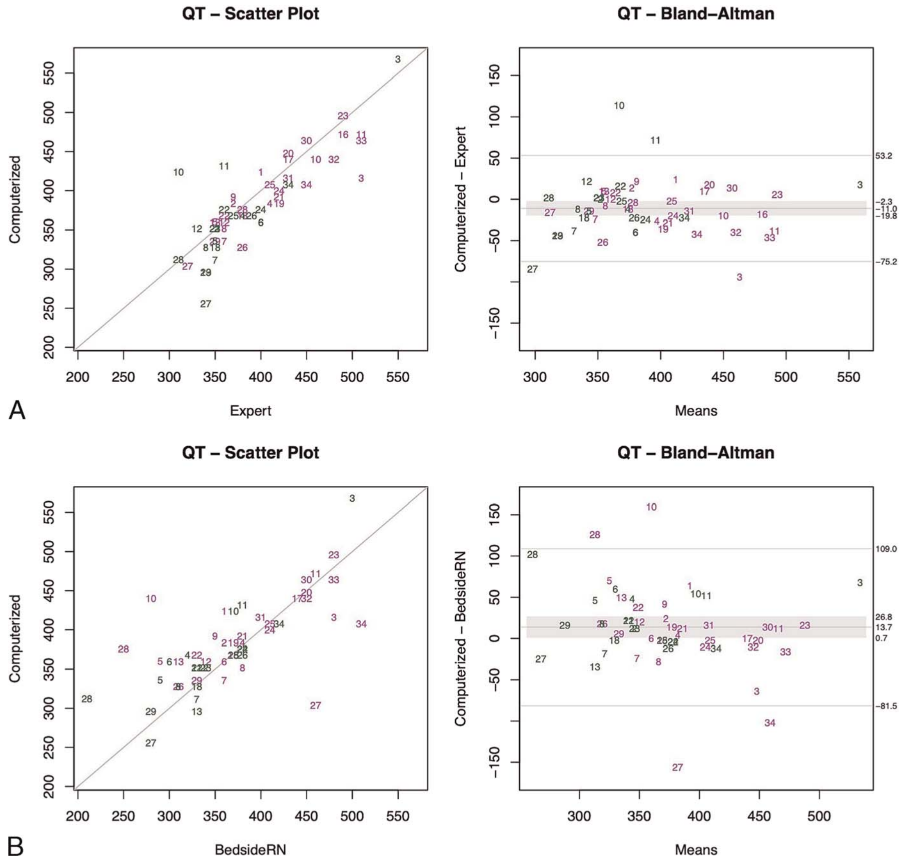

FIGURE 3. *Scatterplots and Bland-Altman plots comparing QT measurements among computerized, expert nurses, and bedside nurses. QT scatterplots (left) and Bland-Altman plots (right) comparing computerized with expert nurses and bedside nurses. The line in the middle of the Bland-Altman figure represents the mean difference (bias), and the gray shading is the upper and lower limits for the 95% confidence interval around the mean difference. The lighter dashed lines above and below the mean difference are the upper and lower limits where 95% of the data lie. Each number represents an individual patient identification number; purple represents time 1 (7 AM shift), and dark green represents time 2 (7 PM shift).*

enlarge the ECG on a central monitoring station screen, making identification of the beginning of the Q-wave and end of the T-wave easier; and (3) the QTc was automatically calculated by the software. This may suggest that e-calipers and the QTc software may produce more accurate QT/QTc measurements made by nurses.

In a study by Pickham et al[6] that examined nurse-measured QT intervals, only 47% accurately measured the QT before an educational intervention. However, the accuracy increased to 99% after an educational intervention. In our study, the QT intervals measured by bedside nurses were in close agreement with those of the expert nurses, suggesting that the nurses included in our study were skilled at measuring the QT. It is worth noting that in the Pickham et al study, a preprinted ECG strip with a very discernible onset/offset of the QT interval was used, and all of the nurses in their study measured the same ECG strip. In our study, a real-time ECG was used to measure the QT as per our hospital's standards of care, yet the bedside nurse measurements were in close agreement with both the expert nurses and the computerized measurements. Of note, in the past 5 years, our hospital has implemented several quality improvement projects specific to measuring QT/QTc and suggests that these efforts likely enhanced the skills of the bedside ICU nurses included in this study.

We found a larger mean bias difference for QT comparisons than Helfenbein and coworkers.[12] However, in their study, QT measurements were made by 1 physician who examined a 2-lead ECG over 1 minute. In contrast, we examined measurements from multiple nurses who made measurements from a snapshot ECG, which could explain these differences. Regardless, the mean bias differences in our study were small and do not seem to have clinical significance. However, given that our sample was small, further research is necessary to confirm these findings before making substantial changes in clinical practice.

The measurement comparisons for QTc also showed a significant mean bias difference. The smallest mean bias was observed between the computerized and expert nurses. Our observed computerized QTc measurements are similar to a study by Janssen et al, who compared manual QTc measurements with continuous

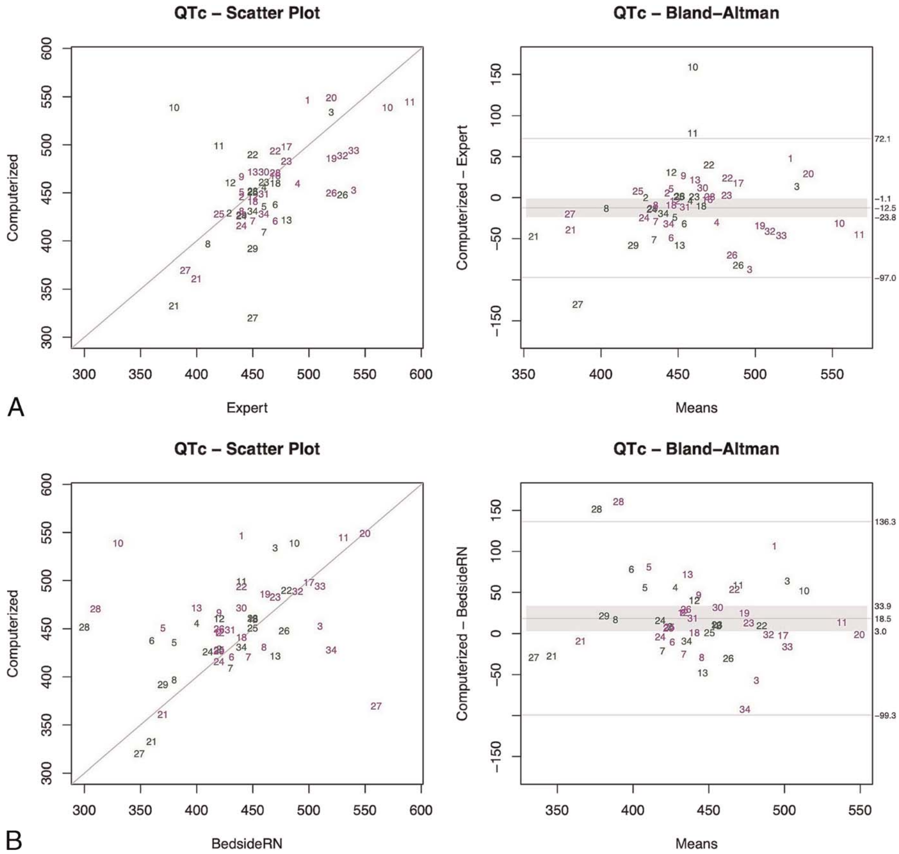

FIGURE 4. *Scatterplots and Bland-Altman plots comparing QTc measurements among computerized, expert nurses, and bedside nurses. QTc scatterplots (left) and Bland-Altman plots (right) comparing computerized with expert nurses and bedside nurses. The line in the middle of the Bland-Altman figure represents the mean difference (bias), and the gray shading is the upper and lower limits for the 95% confidence interval around the mean difference. The lighter dashed lines above and below the mean difference are the upper and lower limits where 95% of the data lie. Each number represents an individual patient identification number; purple represents time 1 (7 AM shift), and dark green represents time 2 (7 PM shift).*

bedside monitor QTc measurements. In their study, the mean bias difference between manual and computerized measurements was 19.5 milliseconds (limit of agreement, −44.6 to 83.7).[11] In this study, continuous computer-generated QTc values (not QT) were compared with manual measurements from lead II of a 12-lead ECG using hand-held calipers rather than e-calipers. As in our study, they found that computerized QTc measurements were in close agreement with manual measurements.

There were larger mean bias differences for QTc comparisons compared with QT measurement. This is not surprising given that both the QT and an R-to-R interval must be measured, which means even minor QT and R-to-R measurement variance will impact the QTc. A study by Pickham et al[6] found that despite education, measurement accuracy among clinical nurses is substandard. In their study, nurses used hand-held calipers, whereas the nurses in our study used e-calipers. The e-caliper software automatically calculates the QTc once the QT and the R-to-R interval are measured, which not only reduces mathematical errors (QTc) but may also help nurses more easily identify the onset/offset of the ECG waveforms used for QT and R-to-R intervals. Given that our results show that the nurse-measured QT/QTc (both bedside and experts) closely matched the computerized measurements, using the latter method in the ICU appears to offer a comparable alternative to manual measurements. However, additional research is needed to compare the accuracy of computerized QT and QTc measurements from the bedside monitor against standard 12-lead ECGs, given that the standard 12-lead ECG is considered the gold standard method.

Our pilot study, conducted on a small sample of ICU patients, showed that computerized QT/QTc measurements from bedside monitors were in close agreement with those made by bedside and expert nurses using e-calipers. This suggests that computerized measurements might be a convenient alternative to nurse-measured QT/QTc, which could reduce the burden placed on nurses when using hand/eye measurements and may increase adherence to practice recommendations. However, implementing broad practice standard changes based on our pilot study should be done cautiously. Regardless of the approach used to measure QT/QTc, education that emphasizes the importance of maintaining

What's New and Important

- Few studies have compared computerized QT/QTc interval measurements with those made by nurses using electronic calipers.
- Although statistical differences were found between measurement methods, the mean bias difference was at most 20 milliseconds (ie, half of 1 small box on an electrocardiographic paper grid) and does not seem to be clinically significant.
- Computerized QT/QTc measurements seem to be a suitable alternative to nurse-measured QT/QTc, which could reduce inaccuracies and enhance adherence to practice standards.

measurement consistency, establishing a standard procedure for serial measurements, consistent ECG lead(s) selection, and how to identify the QRS onset and end of the T-wave as per established standards is essential.[1,5] In addition, it would be prudent to validate the accuracy of QT/QTc measurements that are close to the clinically important 500-millisecond cut point, by recording a resting 12-lead ECG and/or verifying the measurement with a second nurse.

Limitations

Several limitations are worth noting. First, we anticipated having 92 QT/QTc measurements for comparison in the 46 patients being treated in the ICU on the 2 days we collected data. However, only 34 (74%) patients had a QT/QTc measurement documented, and in 10 (29%), only 1 measurement had been obtained (ie, either the 7 AM or 7 PM nurse did not perform the measurement). Hence, adherence to our hospital's practice standard had not been met. Although a small portion of the missing data was explainable (eg, low-quality ECG waveform, atrial fibrillation, artifact, and no discernible T-wave), the measurement had simply not been performed in most patients and limited our ability to make comparisons. This finding is consistent with a study comparing baseline, 3-month, and 4–6-month documentation rates following a computerized best-practice advisory intervention, highlighting the challenges of adherence to practice standard recommendations.[23] Second, although the nurses, both experts and bedside, measured the QT/QTc using an ECG from the same date/time, the computerized measurements were not always available at the same date/time. Therefore, there is the potential for measurement bias in our comparisons. However, the mean time difference was, on average, 1 minute 19 seconds, except in 1 case where there was a 1 hour 45 minute difference. However, the QT/QTc measurements were in close agreement in this 1 patient. Our overall findings showed that the expert nurses, who collaborated on the QT/QTc measurements, tended to measure the longest QT/QTc as compared with the computerized and bedside nurses, which is another potential bias in our study. Third, the computerized software used 4 ECG leads in its calculation, whereas we used 2 leads (II and V1) and used e-calipers and may account for the QT/QTc measurement variations we found. Fourth, we did not collect data from the bedside nurses, so it is possible that an individual nurse(s) was included more than once and we did not examine their skill level using e-calipers. However, the goal of this study was to examine "real-world" nursing practice related to QT/QTc measurements and compare these to expert nurses and computerized measurements. Finally, our study included a small sample of ICU patients from 1 hospital during only 2 days of data collection, which limits the generalizability of our findings. A larger prospective study, including non-ICU patients and an evaluation of computerized measurement comparisons with a standard 12-lead ECG, the noninvasive gold standard, is warranted.

Conclusion

Computerized QT/QTc measurements calculated from the bedside monitor software and measurements performed by bedside and expert nurses were in close agreement. Although statistically significant differences were found, the mean bias difference was less than 20 milliseconds, or half of a small box on the ECG paper and therefore does not seem to be clinically significant. However, given our findings, it would be prudent to validate the accuracy of QT/QTc measurements that are close to the clinically important 500-millisecond cut point, by recording a resting 12-lead ECG and/or verifying the measurement with a second nurse. This suggests that computerized measurements might be a suitable alternative to nurse-measured QT/QTc, which could reduce inaccuracies and burden on nurses and may increase adherence to practice recommendations. Additional research comparing computerized QT/QTcs from bedside monitors with the standard 12-lead ECG in a larger sample, including non-ICU patients, is needed.

REFERENCES

1. Sandau KE, Funk M, Auerbach A, et al. Update to practice standards for electrocardiographic monitoring in hospital settings: A scientific statement from the American Heart Association. *Circulation*. 2017;136(19):e273–e344. doi:10.1161/CIR.0000000000000527.
2. Pickham D, Helfenbein E, Shinn JA, et al. High prevalence of corrected qt interval prolongation in acutely ill patients is associated with mortality: results of the QT in practice (QTIP) study. *Crit Care Med*. 2012;40(2):394–399. doi:10.1097/CCM.0b013e318232db4a.
3. Drew BJ, Califf RM, Funk M, et al. Practice standards for electrocardiographic monitoring in hospital settings: An American Heart Association scientific statement from the Councils on Cardiovascular Nursing, Clinical Cardiology, and Cardiovascular Disease in the Young: endorsed by the

International Society of Computerized Electrocardiology and the American Association of Critical-Care Nurses. *Circulation*. 2004;110(17):2721–2746. doi:10.1161/01.CIR.0000145144.56673.59.

4. Pickham D, Helfenbein E, Shinn JA, Chan G, Funk M, Drew BJ. How many patients need QT interval monitoring in critical care units? Preliminary report of the QT in practice study. *J Electrocardiol*. 2010;43(6):572–576. doi:10.1016/j.jelectrocard.2010.05.016.
5. Drew BJ, Ackerman MJ, Funk M, et al. Prevention of torsade de pointes in hospital settings: A scientific statement from the American Heart Association and the American College of Cardiology Foundation. *Circulation*. 2010;121(8):1047–1060. doi:10.1161/CIRCULATIONAHA.109.192704.
6. Pickham D, Shinn JA, Chan GK, Funk M, Drew BJ. Quasi-experimental study to improve nurses' QT-interval monitoring: results of QTIP study. *Am J Crit Care*. 2012;21(3):195–200. doi:10.4037/ajcc2012245.
7. Viskin S, Rosovski U, Sands AJ, et al. Inaccurate electrocardiographic interpretation of long QT: the majority of physicians cannot recognize a long QT when they see one. *Heart Rhythm*. 2005;2(6):569–574. doi:10.1016/j.hrthm.2005.02.011.
8. Bogossian H, Linz D, Heijman J, et al. QTc evaluation in patients with bundle branch block. *Int J Cardiol Heart Vasc*. 2020;30:100636. doi:10.1016/j.ijcha.2020.100636.
9. Patel PJ, Borovskiy Y, Killian A, et al. Optimal QT interval correction formula in sinus tachycardia for identifying cardiovascular and mortality risk: findings from the Penn Atrial Fibrillation Free Study. *Heart Rhythm*. 2016;13(2):527–535. doi:10.1016/j.hrthm.2015.11.008.
10. Vink AS, Neumann B, Lieve KVV, et al. Determination and interpretation of the QT interval. *Circulation*. 2018;138(21):2345–2358. doi:10.1161/CIRCULATIONAHA.118.033943.
11. Janssen GH, Rijkenberg S, van der Voort PH. Validation of continuous QTc measurement in critically ill patients. *J Electrocardiol*. 2016;49(1):81–86. doi:10.1016/j.jelectrocard.2015.10.001.
12. Helfenbein ED, Zhou SH, Lindauer JM, et al. An algorithm for continuous real-time QT interval monitoring. *J Electrocardiol*. 2006;39(4 suppl):S123–S127. doi:10.1016/j.jelectrocard.2006.05.018.
13. Cvach M. Monitor alarm fatigue: an integrative review. *Biomed Instrum Technol*. 2012;46(4):268–277. doi:10.2345/0899-8205-46.4.268.
14. Fidler RL, Pelter MM, Drew BJ, et al. Understanding heart rate alarm adjustment in the intensive care units through an analytical approach. *PloS One*. 2017;12(11):e0187855. doi:10.1371/journal.pone.0187855.
15. Winters BD, Cvach MM, Bonafide CP, et al. Technological distractions (part 2): a summary of approaches to manage clinical alarms with intent to reduce alarm fatigue. *Crit Care Med*. 2018;46(1):130–137. doi:10.1097/ccm.0000000000002803.
16. Helfenbein ED, Ackerman MJ, Rautaharju PM, et al. An algorithm for QT interval monitoring in neonatal intensive care units. *J Electrocardiol*. 2007;40(6 Suppl):S103–S110. doi:10.1016/j.jelectrocard.2007.06.019.
17. Luo S, Michler K, Johnston P, Macfarlane PW. A comparison of commonly used QT correction formulae: the effect of heart rate on the QTc of normal ECGs. *J Electrocardiol*. 2004;37(suppl):81–90. doi:10.1016/j.jelectrocard.2004.08.030.
18. Philips. *Instructions for Use: Intellivue Patient Monitor: Mx400/450/500/600/700/800*. Germany: Philips; 2013. https://medaval.ie/docs/manuals/Intellivue-Manual.pdf. Accessed September 10, 2023.
19. Altman DG, Bland JM. Measurement in medicine: the analysis of method comparison studies. *J R Stat Soc Series D (The Statistician)*. 1983;32(3):307–317. doi:10.2307/2987937.
20. Lehnert B. M.B. L. Package ‘blandaltmanleh'. 2021. https://cran.r-project.org/web/packages/BlandAltmanLeh/index.html. Accessed August 30, 2021.
21. R Core Team. R: a language and environment for statistical computing. R Foundation for Statistical Computing. 2021. https://www.R-project.org/. Accessed August 30, 2021.
22. Bates D, Machler M, Bolker BM, Walker SC. Fitting linear mixed-effects models using lme4. *J Stat Software*. 2015;67(1):1–48. doi:10.18637/jss.v067.i01.
23. Sandau KE, Sendelbach S, Fletcher L, Frederickson J, Drew BJ, Funk M. Computer-assisted interventions to improve QTc documentation in patients receiving QT-prolonging drugs. *Am J Crit Care*. 2015;24(2):e6–e15. doi:10.4037/ajcc2015240.