# Comparison of QT and QTc Interval Measurements from Bedside Electrocardiograms between Expert Nurses, Bedside Nurses, and Computerized Measurements: A Pilot Study

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THESIS
Submitted in partial satisfaction of the requirements for degree of
MASTER OF SCIENCE

in

Nursing

in the

GRADUATE DIVISION
of the
UNIVERSITY OF CALIFORNIA, SAN FRANCISCO

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## Acknowledgments

First and foremost, I want to thank my advisor, Dr. Pelter, for her guidance and support throughout this entire process. Your leadership, depth of knowledge, wisdom, and steady presence provided me with invaluable mentorship throughout this journey, both professionally and personally. I am eternally grateful.

Dr. Mackin, your profound insights and knowledge about all subject matter have provided me guidance for continued growth, both professionally and personally.

To collaborators across the clinical practice: Shelvin Prasad, Gopi Ganesh, Dr. Thomas Hoffman, Dr. Hildy Schell-Chaple, Amy Larsen, Cass Sandoval, and Sarah Berger.

To UCSF Health and the UCSF School of Nursing for funding this study with the Clinical Nurse Research grant.

To my husband, thank you for your unconditional love, endless support, and continued encouragement in all my endeavors.

Comparison of QT and QTc Interval Measurements from Bedside Electrocardiograms between Expert Nurses, Bedside Nurses and Computerized Measurements: A Pilot Study

Karolina Ho

## Abstract

**Introduction**: Prolongation of the QT/QTc (heart rate corrected) >500 milliseconds (msec) measured on the electrocardiogram (ECG) in hospitalized patients is associated with torsade de pointes (TdP). While some bedside ECG monitors now offer continuous QT/QTc software, agreement of these measurements to bedside and/or expert nurses has not been evaluated. **Purpose**: The purpose of this study was to compare QT/QTc measurements between expert nurses, bedside nurses, both using electronic calipers, and continuous computerized measurements. **Methods**: Prospective observational study in three intensive care units (ICUs). Up to two QT/QTc measurements per patient were examined. QT/QTc agreement was examined using Bland-Altman analysis. **Results**: The study included 34 ICU patients with 57 QT/QTc measurements. Table of results:

| Comparison Group | Bias (Mean, SD) | 95% CI | 95% LOA Lower, Upper | p-value |
|---|---|---|---|---|
| **QT** | | | | |
| Computerized vs expert | -11.04 (4.45) | (-2.3, -19.8) | (-75.2, 53.2) | 0.016 |
| Bedside RN vs expert | -25.17 (5.99) | (-13.4, 36.9) | (-113.7, 63.4) | <0.001 |
| Computerized vs bedside nurse | -13.72 (6.66) | (-0.7, -26.8) | (-109, 81.5) | 0.044 |
| **QTc** | | | | |
| Computerized vs expert | -12.46 (5.80) | (-1.1, -23.8) | (-97, 72.1) | 0.035 |
| Bedside RN vs expert | -31.33 (7.70) | (-16.2, -46.4) | (-146, 83.4) | <0.001 |
| Computerized vs bedside nurse | -18.49 (7.90) | (-3.0, -33.9) | (-136.3, 99.3) | 0.022 |

**Conclusion**: Expert nurses consistently measured a longer QT/QTc as compared to bedside nurses and computerized measurements and computerized measurements were consistently longer than bedside nurse measurements. While there was a statistical difference between QT/QTc measurements between groups, the differences do not appear to be clinically

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significant due to the small mean bias differences. However, future studies are warranted to corroborate our findings and should include comparisons to standard 12-lead ECG QT/QTc measurements.

*Keywords:* electrocardiographic monitoring, intensive care unit, measurements, QT/QTc, nurse measured, computerized measurements

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ECG: Electrocardiogram

QT: QT interval

QTc: QT corrected

**Introduction**

In hospitalized patients, prolongation of the QT and QTc (corrected for heart rate) measured from the electrocardiogram (ECG) is associated with torsade de pointes (TdP), a polymorphic ventricular tachycardia. Given that TdP can deteriorate into ventricular fibrillation and even death, early identification of QT/QTc prolongation followed by appropriate clinical interventions (i.e., magnesium, discontinuing QT/QTc prolonging medication[s]) can avert this potentially lethal arrhythmia.[1] One study found a 24% prevalence rate of QT/QTc prolongation (i.e.,>500 milliseconds >15 minutes) among 1,039 consecutive intensive care unit (ICU) patients.[2] Furthermore, patients with QT/QTc prolongation had a longer length of hospitalization (276 hours vs. 132 hours, $p < .0005$) and all-cause mortality (OR 2.99; 95% CI 1.1–8.1) as compared to patients without QT prolongation.[2] This study shows that nearly one-quarter of ICU patients have QT/QTc prolongation and these patients are at increased risk for untoward outcomes.

The most recently published Practice Standards for in-hospital ECG monitoring define QT/QTc interval monitoring as a high priority in at-risk patients and recommend that hospitals establish uniform protocols for QT/QTc monitoring for all health care providers.[1, 3] Specific recommendations include: defining a standard procedure for serial measurements; defining criteria for selection of ECG lead(s) to use and consistently use this same lead(s) for subsequent measurements; defining how to identify the onset of the QRS and the end of the T-wave; document QT/QTc every 8-12 hours and more frequently when QT/QTc prolonging drug(s) are administered; and/or when identified patient risk factors are present.[1, 3] While there are known demographic and clinical characteristics that place patients “at-risk” (i.e., heart disease, older age, female gender, impaired renal and/or hepatic function, QT/QTc prolonging medications, polypharmacy, electrolyte imbalance, or 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 the QT/QTc and be able to identify at-risk patients.

While careful monitoring for QT/QTc interval prolongation is standard practice, multiple measurement challenges have been identified. For example, beat-to-beat T-wave variability contributes to the inability to precisely identify the end of the T-wave and thus directly affects accurate QT/QTc measurements.[5] Challenging ECG waveforms (i.e., notched or biphasic T-waves, artifact) and rhythm abnormalities (i.e., atrial fibrillation/flutter, right or left bundle branch block (BBB), ventricular paced rhythms, and tachycardia) also make it difficult to measure the QT/QTc accurately. In addition, multiple QT onset and offset methods have been proposed (i.e., QTc Tangent or QTc threshold to identify end-of-the T-wave) as have a variety of QT heart rate correction formulas (i.e., Bazzett, Fridericia, Framingham, Hodges) adding complexity to QT/QTc measurements.[5-8] In one study of 877 physicians (from 12 countries), only 36% of the cardiologists and 31% of non-cardiologists participating identified a prolonged QT interval in patients with long QT syndrome.[9] In another study that examined 379 nurses, less than half of nurses correctly measured the QT interval, and only 6% accurately calculated the QTc.[10] The latter is due to the complex formulas, often done by hand, that are used to correct the QT interval for heart rate. These studies illustrate the challenges associated with accurate QT/QTc measurements.

Most hospitals use manual QT/QTc measurement methods. However, some bedside monitoring manufacturers now have available computerized QT/QTc software algorithms, which automatically and continuously measure both the QT and QTc.[1, 4, 11, 12] In addition, some bedside ECG monitoring manufacturers now include electronic calipers for use by nurses to measure the QT and then automatically calculate the QTc. Computerized and continuous QT/QTc monitoring software has several advantages. First, the software is added to the existing bedside ECG monitor, eliminating the need for manual measurements and extra equipment (i.e., hand-held calipers, calculator). Second, the bedside monitor visually displays continuous QT/QTc values derived from multiple ECG leads, allowing clinicians to view the QT/QTc value at any given time. Finally, computerized QT/QTC software includes an alarm feature designed to alert clinicians to QT/QTc changes, or a “delta-QT” (i.e., change of QT/QTc >60% from established baseline), with the goal of early interventions to prevent TdP. However, while computerized QT/QTc software is available, some hospitals have been hesitant to activate these types of alarms due to the possibility of enhancing alarm fatigue.[13-15] In addition, some hospitals question the accuracy of computerized QT/QTc measurements compared to nurse measured, either manually or with electronic calipers.

Therefore, the purpose of this pilot study was to compare QT/QTc measurements in an intensive care unit (ICU) sample between: (1) bedside clinical nurses using electronic calipers; (2) computerized measurements from the bedside monitor; and (3) expert nurse measurements using electronic calipers.

## Methods

### *Study Design*

This prospective observational study was conducted at a 600-bed academic medical center in the western United States. The following adult critical care units were included: neurological intensive care unit (ICU) (n= 16), medical/surgical ICU (n=16 beds), and a cardiac ICU (n=14 beds). The Institutional Review Board approved the study with a waiver of patient consent due to the purely exploratory design of the study, and identifiable patient data was not collected (IRB# 21-34690).

*Sample*

The unit of analysis for this study was QT/QTc interval measurements made by bedside nurses, computerized, and expert nurses. However, we also collected patient age, sex, and ICU unit for the sample. Data were collected by our research team on two different days and were separated by a two-week period to minimize repeat patients and nurses. The standard procedure at our hospital is to measure ECG waveforms (i.e., PR-interval, R-to-R, QRS duration, and QT/QTc) at the start of each 12-hour shift (7 AM and 7 PM). For this study, we examined only the QT/QTc measurement. We obtained up to two QT/QTc measurements for each patient, those made by the morning shift bedside nurse and the night shift bedside nurse from the prior evening. On each data collection day, the total daily patient census in the three ICUs could reach 46; hence, we anticipated 92 QT-QTc measurements (i.e., two for each patient).

*QT/QTc Measurements*

*Computerized QT/QTc*

The bedside ECG monitor in use during the study included QT/QTc software and was used for the computerized measurements (Philips Healthcare, IntelliVue MX800, Cambridge, MA). The bedside monitor uses a 5-lead ECG configuration and records leads I, II, III, aVR, aVL, aVF, and a V lead, which is V1 at our hospital. The software calculates the QT/QTc in leads I, II, III, and the V lead and produces a “global” QT/QTc measurement.[12, 16, 17] The QT/QTc algorithm performs QT analysis at 15-second intervals and calculates an average heart rate with each interval to determine the QTc. The Bazett’s formula was used as the default setting to calculate the QTc. The QT/QTc is updated every 1-minute and is continuously displayed on the bedside monitor. Historical QT/QTc data are stored with a date and time stamp in the monitor.

When the QT/QTc cannot be reliably analyzed by the software (i.e., atrial fibrillation, flat T-waves, artifact, small R-waves, or QT out of range [<200 or >800 milliseconds]), an inoperative message alert occurs and the QT/QTc is not calculated.

*Bedside Nurse Measurements*

The bedside ICU nurse measured the QT/QTc interval from the bedside ECG monitor, per our hospital's standard protocol, using electronic calipers. Measurements were typically performed in lead II, and V1, which are the default leads displayed on the hospital's bedside ECG monitor. However, the bedside nurse can change the display leads if they choose to view the other available leads, which is done infrequently. Figure 1 illustrates the electronic caliper method used by the bedside nurse. As mentioned above, the standard protocol at our hospital is for the bedside nurse to measure and document ECG intervals (i.e., PR, QRS, RR, and QT/QTc) for their patient at the beginning of their shift or as clinically indicated (i.e., arrhythmia, new/change to QT-prolonging medication, physician/provider order). For this study, we obtained up to two QT/QTc measurements for each patient, those made by the morning shift bedside nurse and the night shift bedside nurse from the prior evening.

*Expert Nurse Measurements*

Four nurse researchers performed the QT/QTc measurements using the same electronic calipers as used by the bedside nurse, which served as the gold standard measure for this study. Three of the data collectors were ICU nurses working in one of the ICU units included in the study, and one data collector was a Ph.D. prepared nurse scientist with ECG expertise. To achieve internal consistency, the experts measured the QT/QTc at the same date and time as the bedside nurse measurements. To ensure reliability, the QT/QTc measurements were performed by one expert nurse and confirmed by two additional experts standing side-by-side when the measurements were performed. The same process the bedside nurses use (as described in Figure 1) was used by the expert nurses.

*Comparisons Between Computerized, Bedside Nurse and Nurse Expert*

The date/time of the bedside nurse measured QT/QTc was used for comparison to the computerized and expert nurse measurements. The date/time of the measurement comparisons was required to be within 30 minutes of each other to ensure equivalent comparisons were made. Figure 3 illustrates the nurse measured QT/QTc and the computerized QT/QTc used for comparison. The expert nurses used this same date/time to perform their measurements. We anticipated that in a small number of patients, QT/QTc measurements would not be performed due to confounders (i.e., atrial fibrillation, flat T-waves, artifact, small R-waves, or ventricular paced rhythm) or that the nurse had manually disabled the computerized QT/QTc software, which was documented on our data collection form.

*Statistical Analysis*

Descriptive statistics were used to describe the sample and ICU type where QT/QTc measurements were obtained. Data are expressed as means with standard deviations, and percentages. For the analysis, the QT/QTc measured by the expert nurses served as the gold standard measure for comparison to the bedside nurse and computerized measurements. Scatter plots were generated to evaluate the relationships between the bedside nurse, computerized and expert nurse measured QT/QTc. In addition, for each QT/QTc comparison (bedside nurse, computerized and nurse experts), the agreement between the two methods (three pairings) was evaluated using Bland-Altman analysis.[18] This approach included plots of the mean difference in QT/QTc between the two methods against the average of the two measurements. In the case of strong agreement, the mean difference between the two methods is expected to be 0 or close to 0. An advantage of a Bland-Altman analysis is that it can uncover measurement bias (i.e., a significant slope on the regression line of the scatter plot) related to the underlying QT/QTc in the event that one of the two measurement methods was systematically worse at accurately capturing values at either end of the range of all QT/QTc measurements.

The Bland-Altman analysis reports the estimated difference between the two measurements with 95% limits of agreement (LOA) around the estimate (mean difference of ±1.96 SD). The mean difference and confidence intervals were determined by a linear mixed model, to properly account for the duplicates (one patient with two QT/QTc measurements). Statistically significant differences were noted at a p-value of <0.05. Descriptive analyses were performed using SPSS version 27 (IBM Corporation, Armonk, NY). The Bland-Altman analysis was performed by a biostatistician using R version 4.0.0 and BlandAltmanLeh package v0.3.1 statistical software.[18-20]

**Results**

A total of 37 patients were included. Of the total, three (8%) patients were excluded because of low-quality ECG waveforms (i.e., artifact, no discernible T-wave); hence, the QT/QTc could not be measured. The final analysis included 34 patients, 16 (47%) were female and 18 (53%) were male. Of the 34 patients, 24 (71%) had two QT/QTc measurements available for analysis and the remaining 10 (29%) patients had only one measurement (either the AM or PM nurse did not perform and/or save the measurement). While we anticipated 68 QT/QTc measurements for comparison (34 patients with two QT/QTc measurements), only 57 (84%) of the QT/QTc measurements were available for comparison. Missing QT/QTc measurements among the bedside nurse group were 11 (16% of 68 possible measurements) and 14 (21% of 68 possible measurements) for the computerized method. Reasons for missing

QT/QTc measurements were as follows: the bedside nurse had not performed and/or saved the measurement, or the computerized software had been turned off. Table 1 shows the patient characteristics, the ICU census on the day of data collection and the QT/QTc measurements available for comparison. In all but one of the QT/QTc measurements, the time differentials were <3 minutes apart. The one exception was a computerized QT/QTc value that was 17 minutes earlier than the bedside nurse and expert nurse measurements.

*Bland Altman Analysis*

The results of the Bland Altman analysis are presented in Table 2. Scatter plots and Bland-Altman plots for the QT measurements are shown in Figure 3, A, B, and C and the QTc measurements in Figure 4, A, B, and C. These figures illustrate the distribution and agreement between the following comparisons: (1) expert nurses versus computerized; (2) expert nurses versus the bedside nurse; and (3) computerized versus bedside nurse measurements.

**Expert nurses versus computerized:** Comparisons for the expert nurses and the computerized **QT** measurements, showed a significant bias difference of -11.04 $\pm$ 4.45 (95% CI -2.3 to -19.8) and LOA of -75.2 to 53.2 were found (Table 2). The LOA showed that the QT measurements were within 75 to 53 milliseconds (milliseconds) for this comparison. Figure 4A shows the scatter plot and Bland-Altman analysis for the expert nurses and the computerized QT measurement comparisons. The linear mixed model was significant (p=0.016).

Comparisons for the expert nurses and the computerized **QTc** measurements, showed a significant bias difference of -12.46 $\pm$ 5.80 (95% CI -1.1 to -23.8) and LOA of -97 to 72 were found (Table 2). The LOA showed that the QTc measurements were within 97 to 72 milliseconds for this comparison. Figure 5A shows the scatter plot and Bland-Altman analysis for the expert nurses and the computerized QTc measurement comparisons. The linear mixed model was significant (p=0.035).

**Expert nurses versus bedside nurse:** Comparisons for the expert nurses and bedside nurse **QT** measurements, showed a significant bias difference of -25.17 $\pm$ 5.60 (95% CI -13.4 to 36.9) and LOA of -113.7 to 63.4 were found (Table 2). The LOA showed that the **QT** measurements were within 114 to 63 milliseconds for this comparison. Figure 4A shows the scatter plot and Bland-Altman analysis for the expert nurses and bedside nurse **QT** measurement comparisons. The linear mixed model was significant (p<0.001).

Comparisons for the expert nurses and the bedside nurse **QTc** measurements, showed a significant bias difference of -31.33 $\pm$ 7.70 (95% CI -16.2 to -46.4) and LOA of -146 to 83.4 were found (Table 2). The LOA showed that the **QTc** measurements were within 146 to 83 milliseconds for this comparison. Figure 5A shows the scatter plot and Bland-Altman analysis for the expert nurses and the bedside nurse **QTc** measurement comparisons. The linear mixed model was significant (p<0.001).

**Computerized versus bedside nurse:** Comparisons for the computerized and bedside nurse **QT** measurements, showed a significant bias difference of -13.72 $\pm$ 6.70 (95% CI -0.7 to -26.8) and LOA of -109 to 81.5 were found (Table 2). The LOA showed that the **QT** measurements were within 109 to 82 milliseconds for this comparison. Figure 4A shows the scatter plot and Bland-Altman analysis for the expert nurses and bedside nurse **QT** measurement comparisons. The linear mixed model was significant (p=0.044).

Comparisons for the computerized and the bedside nurse **QTc** measurements, showed a significant bias difference of -18.49 $\pm$ 7.90 (95% CI -3.0 to -33.9) and LOA of -136.3 to 99.3 were found (Table 2). The LOA showed that the **QTc** measurements were within 136 to 99 milliseconds for this comparison. Figure 5A shows the scatter plot and Bland-Altman analysis for the computerized and the bedside nurse **QTc** measurement comparisons. The linear mixed model was significant (p=0.022).

*QT and QTc measurements >500 Milliseconds not in Agreement*

QT and QTc >500 milliseconds are considered clinically significant as this increases the risk for TdP.[1, 3, 5] Thus, disagreements in measurements that exceeded this value were examined. Table 3 shows disagreements in QT/QTc measurements. In three QT measurements, the expert nurses measured a QT >500 milliseconds, whereas the computerized and bedside nurse measured a QT <500 milliseconds. In one QT measurement, the bedside nurse measured a QT >500 milliseconds and the expert nurses and the computerized QT was <500 milliseconds.

With regards to QTc measurement. In six measurements, the expert nurses measured a QTc >500 milliseconds and both the computerized and bedside nurse QTc were <500 milliseconds. In one QTc, both the experts nurses and computerized method measured a QTc >500 milliseconds and the bedside nurse QTc was <500 milliseconds. In two QTc measurements, the bedside nurse measured a QTc >500 milliseconds and both the expert nurses and the computerized method measured a QTc <500 milliseconds. Finally, in one QTc measurement, the computerized QTc was >500 milliseconds and both the expert nurses and the bedside nurse measured <500 milliseconds.

## Discussion

The overall findings from this pilot study comparing QT/QTc measurements between expert nurses versus bedside nurses (both using electronic calipers) versus computerized measurements showed a significant mean bias for all of the comparisons. The expert nurse consistently measured a longer QT/QTc than bedside nurses and computerized measurements. Computerized measurements were consistently longer than bedside nurse measurements. However, while there was a statistical difference between QT/QTc measurements in all comparisons, these differences are not clinically significant because the mean bias was small. For example, the highest mean bias difference was seen in the QTc comparison between the expert nurses and the bedside nurses (i.e., 31 milliseconds, or 0.03 seconds) and represents less than one small box on the ECG grid markings. This suggests that all three methods' QT/QTc measurements were in close agreement and, therefore, is not likely a clinically significant difference.

*QT Measurement Comparisons*

The measurement comparisons for the QT showed a significant mean bias for all comparisons. The mean bias was the longest for comparison between expert nurses and the bedside nurse, 25 milliseconds (~½ of one small box on the ECG grid markings at a paper speed of 25 millimeters/second). The mean bias was even smaller when comparing the expert nurses versus computerized,11 milliseconds (~1/4 of one small box on the ECG grid paper at a paper speed of 25 millimeters/second) and computerized versus the bedside nurses, 14 milliseconds (~ 1/3 of one small box on the ECG grid paper). While one might argue that the observed differences in our study were due to the same ECG complex (QT) not being measured for comparisons, in all but one of our QT measurements, the time differentials were <3 minutes apart, which is not likely to be the source of the differences. Rather, the small differences are likely due to the expert nurses (four) each contributing to the discussion of the start and end of the QT interval, which likely added subtle nuances to the QT measurements made by the expert nurses.

In a study by Pickham et al., who examined nurses' ability to measure QT intervals found that only 47% accurately measured the QT interval prior to an educational intervention, but this increased to 99% following the educational intervention.[10] In our study, the bedside nurse measured QT intervals were in close agreement to those of the expert nurses suggesting that the nurses in our study were skilled at measuring the QT interval. It is worth noting that in the Pickham et al. study, a pre-printed 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, real-time ECG QT intervals were measured per our hospital's practice standard with a high probability of waveform artifact and other waveform challenges, yet the bedside nurse measurement were still in close agreement to the expert nurses and the computerized measurements.

The mean QT bias in our study (largest 25 $\pm$ 5.6 milliseconds bedside nurse versus expert nurses), were higher than those found by Helfenbein and co-workers, which was 8.1 $\pm$ 40 milliseconds (~1/4 small ECG boxes).[12] However, the manual QT measurements in their study were performed by one physician in 95 cases. In addition, they used two ECG channels over a minute, whereas our measurements were made from snap shot ECGs performed by the patient's bedside nurse. The number of different individuals measuring the QT interval in our study likely explain these differences. Despite our study findings of significant mean bias differences across all QT group comparisons, the differences are small and may not reflect clinically important differences.

*QTc Measurement Comparisons*

The measurement comparisons for QTc also showed a significant bias difference between all comparison groups. The largest mean bias was observed between the bedside nurse and expert nurses (31 milliseconds). The smallest mean bias was observed between the computerized and expert comparisons (12 milliseconds). Our observed computerized QTc measurements are similar to a study done by Janssen et al., who compared manual QTc measurements with continuous bedside monitor QTc. In their study, the mean bias difference between human and computerized measurements was 19.5 milliseconds (LOA -44.6 to 83.7).[11] In their study, continuous computer-generated QTc were compared with manual measurements (not electronic calipers) using lead II from a 12-lead ECG, yet our mean bias differences were similar. The investigators did not examine QT alone, but only QTc. As with our study, they found that computerized QTc measurements were in close agreement to manual measurements. Therefore, using continuous QTc measurements could reduce the burden of having to manually measure QTc, which is more complex then QT alone because of the correction needed for heart rate. Given that QTc is typically performed in all hospitalized patients with ECG monitoring, a computerized alternative is clinically appealing and could help identifying high risk patients before a TdP event.[1, 2, 4] However, our study included a small number of patients and thus should be evaluated in larger and non-ICU population.

The largest QTc mean bias was the agreement between the expert nurses and the bedside nurse group of 31 milliseconds (LOA -146 to 83.4). All of the QTc comparisons had larger measurement bias than their respective QT groups. This is most likely attributed to the need to obtain additional manual measurements (i.e., the R-to-R interval prior to the measured QT) and then calculating the QTc measurement corrected for heart rate. Pickham et al. found that clinical nurses' accuracy in measuring QT and R-to-R intervals was low despite education.[10] It should be noted that once the QT is measured, and if measured too long or too short, the QTc will be impacted and was seen in our QTc results. While the agreement between the measured QTc's were statistically significant, as with the QT the mean bias differences were small and therefore do not appear to be clinically significant. However, further research is needed to compare QTc measurements between bedside nurses, computerized to that of those measured from a standard 12-lead ECG prior to clinical practice changes.

In an examination of QT/QTc >500 milliseconds, which is considered clinically prolonged and requires intervention, in three of the QT measurements the expert nurses measured >500 milliseconds, whereas the computerized and bedside nurse measured <500 milliseconds. In one QT measure the bedside nurse measured >500 milliseconds and both the expert nurses and computerized method were <500 milliseconds. While this was seen in only four measures of QT, our data shows that some patients would exceed the clinically relevant QT value. As expected the QTc, which requires heart rate correction and is based on the QT measurement, there were even higher numbers of disagreements, with the experts measuring QTc >500 milliseconds most often, followed by the bedside nurse, then computerized. These data suggest that interventions could occur more often when expert nurses measured the QT/QTc. A more in-depth analysis for these discrepancies is needed. In clinical practice, it would seem reasonable that when a QT/QTc is found to be >500 milliseconds that a second nurse or physician measure the QT/QTc to confirm this finding prior to aggressive interventions. Another strategy is to examine QT/QTc measures in the preceding hours to determine if the QT/QTc has lengthened over time, which would also add important clinical context prior to interventions.[5, 17]

*Implications for Practice*

In this study, we anticipated a daily census of 46 patients in the three ICUs we included. Therefore, based on our hospital's standard of practice of measuring the QT/QTc at the start of each shift (i.e., AM and PM), we anticipated having up to 92 QT/QTc measurements. However, while the anticipated units census was met (n=46 patients), only 34 (74%) patients had QT/QTc measurements suggesting that the standard practice was not met. For example, in our study while there were 14 patients admitted to the medical/surgical ICU on the day of data collection, only 7 (50%) had QT/QTC measurements available for comparison. While some of the missing data were reasonable (i.e., low-quality ECG waveform, artifact, or no discernible T-wave), in some cases, the measurement had simply not been performed, and reasons for not making the measurement were not documented in the electronic health record. The QT/QTc documentation gaps observed in our study were in line with those observed in a 2015 multi-center quasi-experimental study that included large and small hospitals. [21] The investigators found that 46.2% and 26.2% of QT/QTC were not documented respectively (p<0.001). Our findings indicate that adhering to practice recommendations for QT/QTc monitoring continues to pose challenges. The clinical nurse specialist (CNS) role is focused on disseminating knowledge, promoting evidence-based practice and promoting quality and safety.[22] Developing standards of practice and ensuring adherence to these standards is key to enhancing optimal patient care. Our study illustrates an opportunity for CNSs to assess compliance with standards and educational opportunities about the importance of established standards of care, in this case, QT/QTc measurements.

While this is a pilot in 34 ICU patients, our data show that computerized and bedside nurse measured QT/QTc measurements were in close agreement and may suggest that computerized measurements might be used instead of bedside nurse measured QT/QTc. This could reduce the burden on nurse-measured QT/QTc's every shift and may optimize compliance of QT/QTc assessment every shift. However, caution should be used when making major practice standard changes given the small sample included in this study. Regardless of the approach used to measure QT/QTc, education should emphasize the importance of maintaining consistency for repeated QT/QTc measurements, including defining a standard procedure for serial measurements, identifying a process for ECG lead(s) selection criteria, and methods to detect the onset of the QRS and end of the T-wave as per stated practice standards.[1, 5] In addition, confirmation of QT/QTc measurements with a second clinical colleague would be prudent prior to initiating interventions.[5, 17]

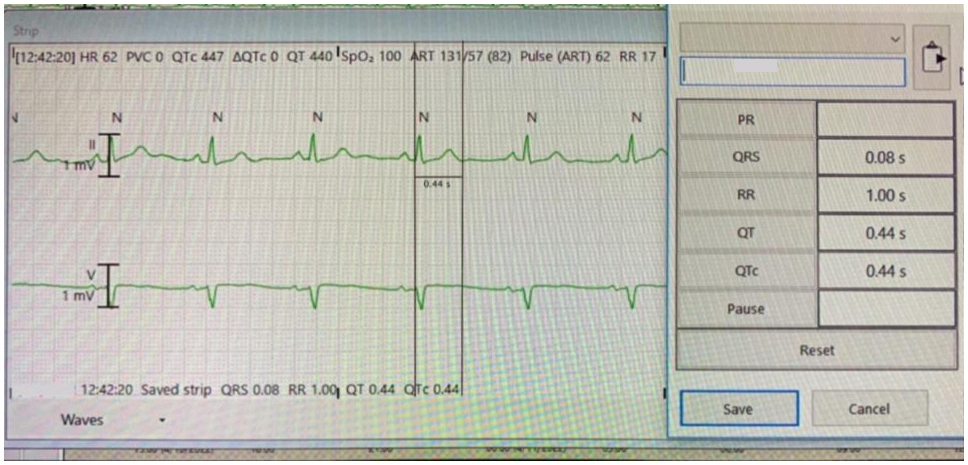
*Strengths and limitations*

While this study appears to be the first to compare QT/QTc measurements in an ICU sample between bedside nurses using electronic calipers, computerized measurement from bedside monitors, and expert nurse measurements using electronic calipers several limitations should be noted. This study examined a small number of ICU patients and was a single-center pilot study with only two days of data collection. However, this pilot study sets the stage for a larger-scale prospective study that should include an evaluation of measurement comparisons with standard 12-lead ECGs. There is the potential that there was measurement bias made by the expert nurses. Four expert nurses collaborated on the measurement points and may have resulted in a bias toward measuring a longer QT, R-to-R interval, which would compound the QTc length as well. However, the measurement differences were small and do not appear to be clinically significant. Of note, was a small number of QT/QTc measurements >500 milliseconds, most often among the expert nurses, which could have clinical implications. We had missing data in both the bedside nurse and computerized measurements making equivalent comparisons challenging. Future studies should examine the extent of ECG practice gap across different institutions and include evaluation of manual and electronic calipers as this tool is increasingly available in bedside monitors.

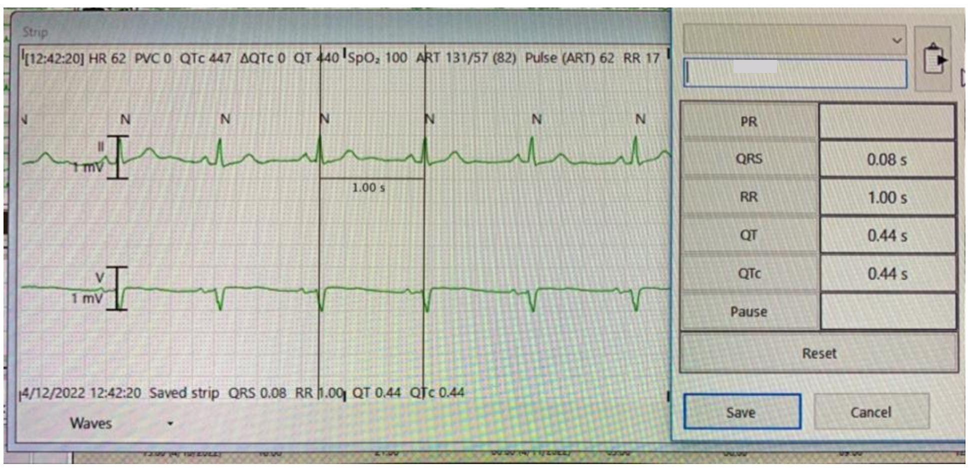
*Conclusion*

In hospitalized patients, lengthened QT/QTc, particularly >500 milliseconds, is associated with TdP.[1] Therefore, accurate measurement of QT/QTc prolongation can identify patients at risk for TdP and its associated complications. However, multiple challenges exist with measuring the QT/QTc interval (i.e., beat-to-beat variability, identifying correct on- and offset of the QT interval, calculating the QTc, and inconsistent nurse measurements).[5-8] While computerized and continuous QT/QTc measurements as well as electronic calipers are now available in some bedside monitors, our study appears to be the first to compare QT/QTc measurements between expert nurses, bedside nurses, and computerized measurements.

In this study, experts nurse consistently measured a longer QT/QTc as compared to bedside nurses and computerized measurements. Computerized measurements were consistently longer than bedside nurse measurements. However, while there was a statistical difference between QT/QTc measurements in all of the comparisons, these differences do not appear to be clinically significant because the mean bias was small (i.e., one small box on the ECG grid markings). However, future studies are warranted to corroborate our findings and should include comparisons to standard 12-lead ECG QT/QTc measurements.




A. QT Interval measurement




B. QT Interval measurement

**Figure 1** Illustration of the electronic calipers to obtain QT/QTc measurements

Illustrates the electronic caliper software feature used to measure QT/QTc from the bedside electrocardiographic monitor. The nurse opens up the electronic caliper software, which allows the nurse to adjust the calipers to the correct location from the start of the QRS to the end of the T-wave. The top image (A) shows how the QT is measured with electronic calipers (black lines). The nurse places the left caliper at the start of the QRS, then the right caliper is placed at the end of the T-wave. Once these locations are identified the nurse clicks the QT button to store the value, which in this example is 0.44 seconds or 440 milliseconds. Next, the nurse calculates the QTc interval using the R-to-R interval before this measured QT. The bottom image (B) illustrates the R-R interval length (black lines = 1.00 second, or 1,000 milliseconds). Once both R-to-R interval is selected the nurse clicks the QTc button and the QTc is automatically calculated. The nurse then clicks “save” to store the values in the monitor with a date and time stamp (bottom of tracing). N= normal QRS complex/beat.

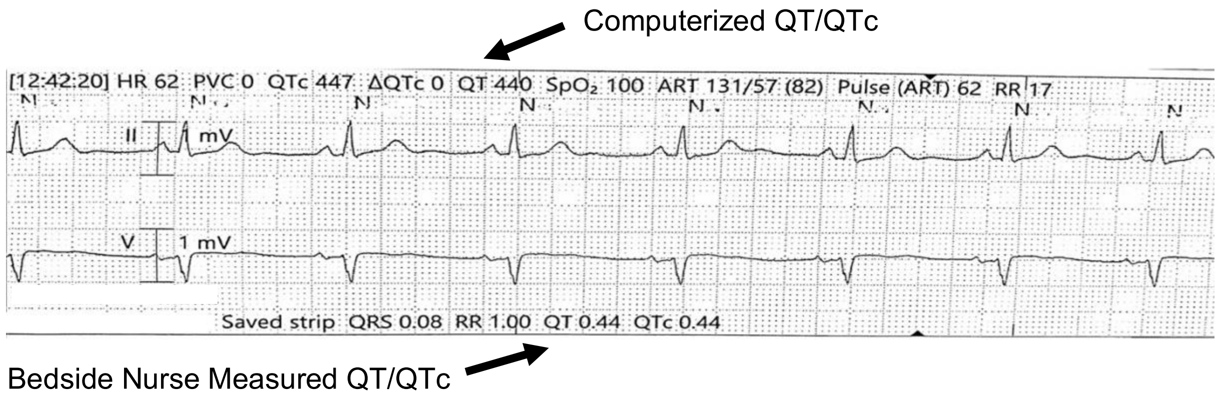



**Figure 2** Two lead ECG rhythm strip with saved QT/QTc measurements

Two lead ECG rhythm strip (II and V1) with bedside nurse performed QT/QTc measurements as noted on the bottom of the tracing (i.e., RR = 1.00 seconds or 60 beats/minute; QT = 0.44 seconds/440 milliseconds; QTc= 0.44 seconds/440 milliseconds). These values are also saved in the bedside monitor. At the top of the rhythm strip are the computerized QT/QTc values (i.e., heart rate=62 beats/minute; QT=440 milliseconds/0.44 seconds; QTc=447 milliseconds/0.44 seconds. **Note the "RR" listed among the computerized measurements is respiratory rate and not R-to-R interval, rather the HR (heart rate) is used to calculate QTc.** As illustrated, the QT/QTc measurements made by the bedside nurse and the computerized method are very similar.

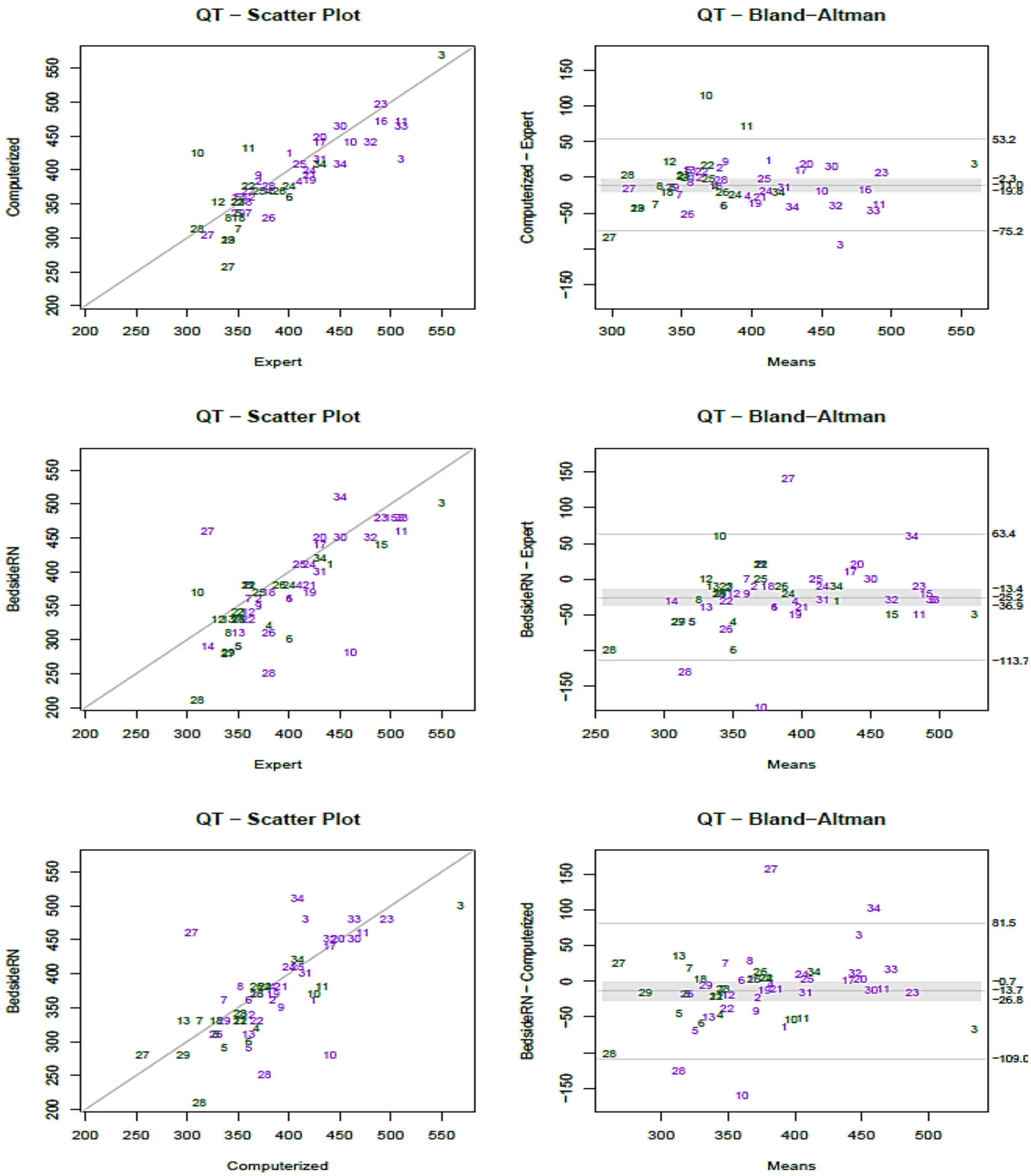



**Figure 3** QT Scatterplots and Bland-Altman plots

Scatterplots (left) and Bland-Altman plots (right) for the following QT interval comparisons: (1) expert nurses versus computerized; (2) expert nurses versus the bedside nurse; and (3) computerized versus bedside nurse measurements. The line in the middle of the Bland-Altman figures represent the mean difference, and the gray shading the upper and lower limits for the 95% confidence interval (CI) around the mean difference. The lighter dashed lines above and below the mean difference are the upper and lower limits for 95% of the data. The number is the patient identification number. The purple values are time 1 (morning shift QT), and dark green is time 2 (night shift QT).

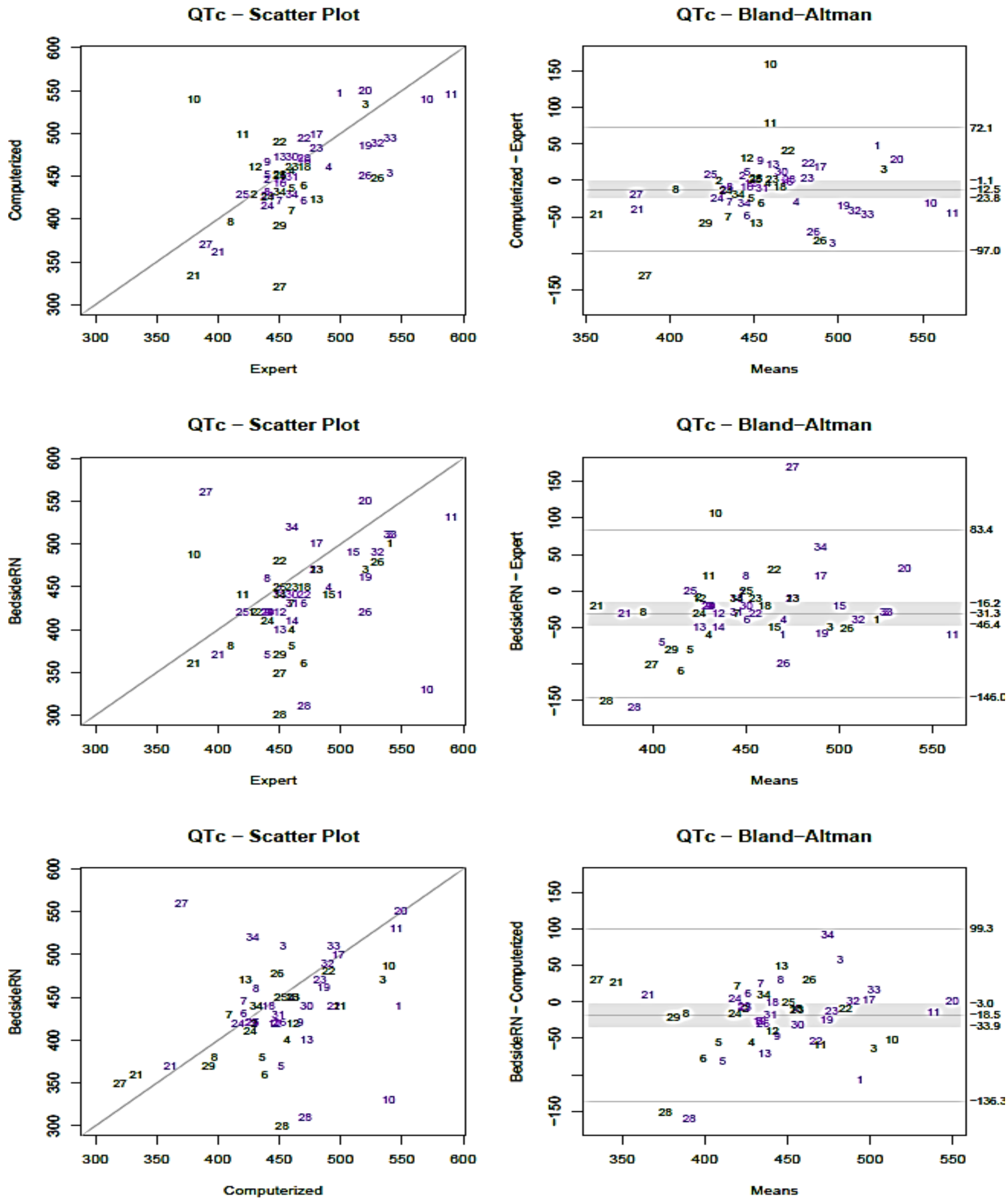



**Figure 4** QTc Scatter plots and Bland Altman plots

Scatterplots (left) and Bland-Altman plots (right) for the following QTc interval comparisons: (1) expert nurses versus computerized; (2) expert nurses versus the bedside nurse; and (3) computerized versus bedside nurse measurements. The line in the middle of the Bland-Altman figures represent the mean difference and the gray shading the upper and lower limits for the 95% confidence interval (CI) around the mean difference. The lighter dashed lines above and below the mean difference are the upper and lower limits for 95% of the data. The number is the patient identification number. The purple values are time 1 (morning shift QT), and dark green is time 2 (night shift QT).

**Table 1** Characteristics of patients and available QT and QTc measurements

Characteristics of 34 intensive care unit patients and available QT and QTc measurements.

| **Characteristic** | **n (%)** | | |
|---|---|---|---|
| **Intensive care unit type** | | | |
| Cardiac (14 beds) | 13 patients | | |
| Medical-Surgical (16 beds) | 7 patients | | |
| Neurological (16 beds) | 14 patients | | |
| Age (mean ± SD, in years) | 62 (± 16) | | |
| Sex | | | |
| Male | 18 (53) | | |
| Female | 16 (47) | | |
| **QT Comparisons available** | Day 1 + Day 2 = total | Day 1 + Day 2 = total | Total |
| Computerized vs expert | 32+22=54 | 34+24=58 | 54 |
| Bedside RN vs expert | 33+24=57 | 34+24=58 | 57 |
| Computerized vs bedside nurse | 32+22=54 | 33+24=57 | 54 |
| **QTc Comparisons available** | | | |
| Computerized vs expert | 32+22=54 | 34+24=58 | 54 |
| Bedside RN vs expert | 33+24=57 | 34+24=58 | 57 |
| Computerized vs bedside nurse | 32+22=54 | 33+24=57 | 54 |
| **Mean (± Standard Deviation) QT/QTc** | **Expert Nurses** | **Computerized** | **Bedside Nurse** |
| QT | 396.76 ± 59.04 | 384.15 ± 56.69 | 370.35 ± 67.53 |
| QTc | 467.03 ± 43.89 | 452.91 ± 49.02 | 435.67 ± 55.39 |

**Table 2** QT and QTc mean difference and limits of agreement

Mean difference and limits of agreement comparing QT and QTc comparisons between measurements made by bedside nurses, computerized and expert nurses. The values shown are milliseconds, which are used to measure QT/QTc values.

| Comparison Group | Bias (Mean, SD) | 95% CI | 95% LOA Lower, Upper | p-value |
|---|---|---|---|---|
| **QT** | | | | |
| Computerized vs expert | -11.04 (4.45) | (-2.3, -19.8) | (-75.2, 53.2) | 0.016 |
| Bedside RN vs expert | -25.17 (5.99) | (-13.4, 36.9) | (-113.7, 63.4) | <0.001 |
| Computerized vs bedside nurse | -13.72 (6.66) | (-0.7, -26.8) | (-109, 81.5) | 0.044 |
| **QTc** | | | | |
| Computerized vs expert | -12.46 (5.80) | (-1.1, -23.8) | (-97, 72.1) | 0.035 |
| Bedside RN vs expert | -31.33 (7.70) | (-16.2, -46.4) | (-146, 83.4) | <0.001 |
| Computerized vs bedside nurse | -18.49 (7.90) | (-3.0, -33.9) | (-136.3, 99.3) | 0.022 |

Abbreviations: CI = confidence interval; LOA = limit of agreement; RN = registered nurse; QT = QT interval measured from electrocardiogram; QTc = heart rate corrected QT interval measured from electrocardiogram SD = standard deviation.
The p-value reports the test of the mean bias using a linear mixed model.

**Table 3** Comparison of measurements with QT/QTc >500 milliseconds

Shows the comparison of QT/QTc measurements between expert nurses, bedside nurses and computerized measures among intensive care unit patients with a QT/QTc >500 milliseconds. This measure is considered clinically important as it increases the risk for Torsades de Point.

| Measurement | Expert Nurses | Computerized | Bedside Nurse |
|---|---|---|---|
| **QT ≥500 milliseconds** | | | |
| #1 | 510 | 416 | 480 |
| #2 | 510 | 472 | 480 |
| #3 | 510 | 464 | 480 |
| #4 | 450 | 408 | 510 |
| **QTc ≥500 milliseconds** | | | |
| #1 | 570 | 539 | 330 |
| #2 | 540 | 494 | 510 |
| #3 | 540 | 453 | 510 |
| #4 | 530 | 489 | 490 |
| #5 | 530 | 490 | 478 |
| #6 | 520 | 461 | 470 |
| #7 | 520 | 486 | 461 |
| #8 | 520 | 450 | 420 |
| #9 | 510 | missing | 490 |
| #10 | 390 | 370 | 560 |
| #11 | 460 | 428 | 520 |
| #12 | 499 | 574 | 440 |

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