

## ORIGINAL ARTICLE

# The QT Scale: A Weight Scale Measuring the QTc Interval

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**Introduction:** Despite the strong evidence of the clinical utility of QTc prolongation as a surrogate marker of cardiac risk, QTc measurement is not part of clinical routine either in hospital or in physician offices. We evaluated a novel device (“the QT scale”) to measure heart rate (HR) and QTc interval.

**Method:** The QT scale is a weight scale embedding an ECG acquisition system with four limb sensors (feet and hands: lead I, II, and III). We evaluated the reliability of QT scale in healthy subjects (cohort 1) and cardiac patients (cohorts 2 and 3) considering a learning (cohort 2) and two validation cohorts. The QT scale and the standard 12-lead recorder were compared using intraclass correlation coefficient (ICC) in cohorts 2 and 3. Absolute value of heart rate and QTc intervals between manual and automatic measurements using ECGs from the QT scale and a clinical device were compared in cohort 1.

**Results:** We enrolled 16 subjects in cohort 1 (8 w, 8 m;  $32 \pm 8$  vs  $34 \pm 10$  years,  $P = 0.7$ ), 51 patients in cohort 2 (13 w, 38 m;  $61 \pm 16$  vs  $58 \pm 18$  years,  $P = 0.6$ ), and 13 AF patients in cohort 3 (4 w, 9 m;  $63 \pm 10$  vs  $64 \pm 10$  years,  $P = 0.9$ ). Similar automatic heart rate and QTc were delivered by the scale and the clinical device in cohort 1: paired difference in RR and QTc were  $-7 \pm 34$  milliseconds ( $P = 0.37$ ) and  $3.4 \pm 28.6$  milliseconds ( $P = 0.64$ ), respectively. The measurement of stability was slightly lower in ECG from the QT scale than from the clinical device (ICC: 91% vs 80%) in cohort 3.

**Conclusion:** The “QT scale device” delivers valid heart rate and QTc interval measurements.

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electrophysiology; long QT syndrome; clinical; noninvasive techniques; electrocardiography

A prolonged QTc has been recognized as a noninvasive risk marker for cardiovascular diseases, sudden death, stroke, and all-cause cardiovascular mortality.<sup>1</sup> With the aging population worldwide, the number of patients exposed to drug therapies with potential QT prolongation effect will increase. However, despite the strong evidence of the clinical utility of QT/QTc prolongation as a surrogate marker of cardiac risk, QT/QTc interval measurement is not part of general clinical routine either inside the hospital or in regular physician offices. Recently, this lack of awareness about a patient susceptibility to develop QT-related arrhythmias has been highlighted in a

statement of the American Heart Association,<sup>2</sup> emphasizing the need to integrate QT monitoring in hospital to reduce the number of torsades de pointes (a life-threatening cardiac arrhythmia).

In this project, we describe a proof-of-concept study evaluating the ability of a new type of device designed to quickly perform a QT/QTc interval measurement at the time of a medical visit. The so-called QT scale is a technical solution to enable healthcare providers to get a patient's heart rate and QTc intervals without using a standard ECG recorder and without significantly changing their medical routines. We present a preliminary evaluation of this device to deliver QT/

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QTc interval measurements in three cohorts of patients: general subjects (cohort 1), cardiac patients going through the inpatient clinic (Clinical Cardiology Division at the University of Rochester Medical Center, Rochester, NY, USA) (cohort 2), and patients with atrial fibrillation (AF) hospitalized for dofetilide treatment (cohort 3). We opted to use the ECG from the second cohort as a learning set in order to develop a reliable fully automatic QT measurement algorithm for ECG signals recorded with the QT scale. Thereafter, we evaluated the measurement technique in the remaining cohorts (1 and 3). We assessed the ability of the device to measure the QT interval in healthy subjects and more challenging set of ECGs with nonsinus rhythm and drug-induced changes in QT intervals.

## METHODS

### Study Populations and Protocol

We enrolled two cohorts of cardiac patients and one cohort of healthy individuals.

#### Cohort 1

This first cohort includes healthy individuals (noncardiac patients) enrolled inside a single private organization (iCardiac Technologies Inc., Rochester, NY, USA). A single ECG signal was recorded in each individual using a clinical 12-lead ECG system and the QT scale device to test the ability of the QT scale to records the ECG signal. These ECGs were recorded simultaneously while the subjects were comfortably sitting in a chair. The subject kept their socks on during the recording. The data from this first cohort was used to first evaluate the hardware of the QT scale and second assess its ability to deliver accurate heart rate and QTc interval measurements.

#### Cohort 2

The cohort 2 included cardiac patients from the Inpatient Clinic at the University of Rochester Medical Center (Rochester, NY, USA). Purposely, any cardiac patients with very diverse type of cardiac diseases were enrolled (inpatients). In this cohort, two clinical ECGs were acquired 1 minute apart, and then the subject was asked to stand for a couple of minutes and step on the weight scale to acquire two scale ECGs 1 minute apart.

#### Cohort 3

The third cohort (cohort 3) included patients going through a dofetilide protocol for drug-induced cardioversion of atrial fibrillation. We selected this cohort for two reasons: (i) this drug induces dramatic effect on the T wave morphology (Ikr blocker) by flattening its amplitude and therefore will challenge the automatic QT interval measurements, and (ii) these patients will be in AF during their first ECG. Three recording sessions per subject were implemented in this cohort: session 1, baseline recording prior to first dose of dofetilide; session 2, prior to second dose of dofetilide; and session 3, prior to hospital release and just after last dose administration. During each session, we acquired two ECGs (replicate ECGs) in standing position on the scale (SCALE) and two ECGs using a clinical 12-lead ECG in supine position. The subjects in cohort 3 were in AF rhythm during their baseline recordings and possibly in the subsequent ones.

The enrollment criteria were similar for the two cohorts of cardiac patients (cohorts 2 and 3), i.e., adult cardiac patients (age  $\geq 18$  years). We excluded patients who could not comply with the use of the weight scale and patients with muscular tremors and/or Parkinson disease. The protocol was approved by the University of Rochester (Rochester, NY, USA) Research Review Board.

### The Clinical ECGs

From the clinical 12-lead ECG devices (clinical ECG), the QT and RR measurements were extracted from commercial systems: the M12A (Global Instrumentation, Syracuse, NY, USA) for cohort 1 and the RR intervals were measured by Hscribe (Mortara Instruments, Milwaukee, WI, USA) for cohorts 2 and 3. The manual measurements of the QT intervals were extracted from lead II by ECG experts (Manual) using paper tracings printed from the clinical device and measured on computer screen for the scale ECGs.

### The QT Scale

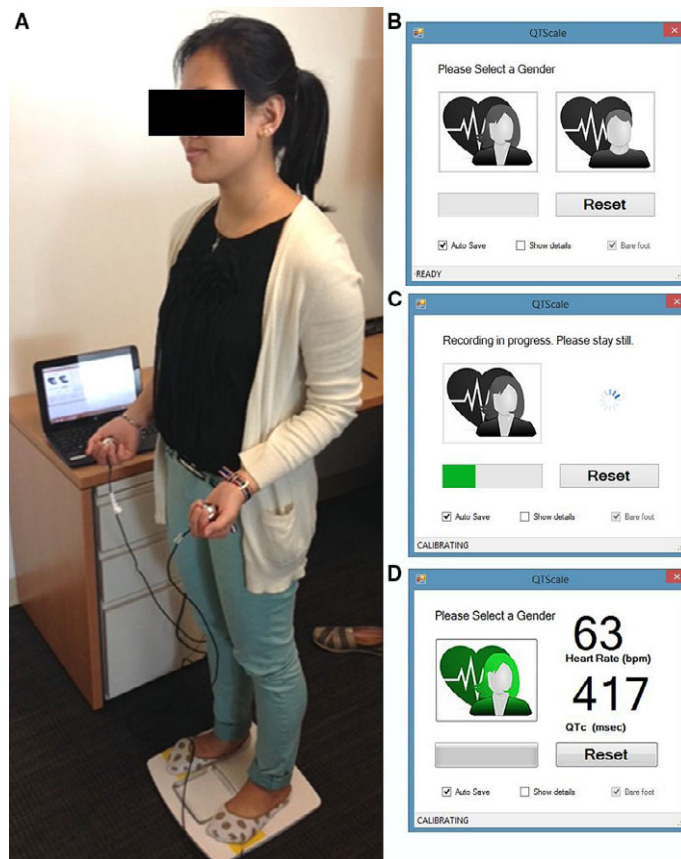
The QT scale prototype is a simple electronic weight scale (commercially available) to which a set of four sensors have been integrated to measure the body surface ECG from the subjects limbs. These sensors are designed to be in contact

with the feet of the patient when he/she steps on the scale, and the two remaining sensors are hand sensors with the shape of a chicken egg (Fig. 1). The four-hand and feet electrodes are connected to a box that contains the electronic components for the recording and the processing of the signal acquired from the subjects limbs. System bandwidth is 0.05–100 Hz, resolution 16 bit, and sampling rate 1 kHz. The QT scale is connected to a laptop (running on its battery) through USB 3.0 port, which delivers 5.00 V power source. The hand and feet electrodes were disinfected using alcohol-based sanitizer. This device complies with the FDA 809.10(c), and it does not require an invasive sampling procedure that presents significant procedure energy into a subject, and it is not designed to introduce energy

into the subject. The prototype used in this study will be ultimately designed to embed all pieces described in Figure 1B in one single device unit (the scale).

### QT and RR Measurements from the Scale ECG Device

From the QT scale device (Scale ECG), we measured heart rate automatically (Scale ECG RR), while QTc interval were measured both manually (Scale ECG Manual QTc) and automatically (Scale ECG Automatic QTc) from all limb leads recorded by the scale device (using a representative beat approach). The algorithm for QRS onset and T wave end detection was designed based on manual annotation from data of the cohort 2. We



**Figure 1.** The “QT scale” is a device integrating both a weight scale and an ECG recorder. It records the ECG signals from the limb leads (Einthoven triangle, i.e., leads I, II, and III). The device includes both feet and hand sensors to record a three-lead electrocardiogram and to deliver the measurements of heart rate and heart rate–corrected QT measurements. (A) the prototype in use; (B) the device schematic presentation; (C) the user interface of the system for gender selection; (D) the screen display during recording, and (E) the user interface reporting the measurements. The system requires the subject to be standing for 60 seconds.

expected lower quality of the ECG signals recorded with the QT scale device (Scale ECG) than with the clinical ECG devices<sup>3</sup> because of the higher impedance of skin–electrode interface for dry electrodes and electromyogram noise when the subject is standing.

We developed a set of digital processing procedures to strongly reduce the noise of the ECG signal and enhance the QRS and repolarization signal (ST-T segment). These procedures include multiple components: signal noise estimation, lead consistency check, and combination of lead signals (root mean square signals). The QRS detection algorithm is a unique fully automatic method based on (i) an adaptive threshold detection of cardiac beats, (ii) computation of a beat template, and (iii) a cross-correlation technique using the beat template to eliminate the beats with inconsistent morphology. Subsequently, a template-based signal-averaging technique is recomputed and used to generate a final representative beat from which QTc intervals are measured. The system includes two different algorithms for the identification of the end of the T wave. The average results from the two methods are reported (differential threshold and slope intercept methods).<sup>4</sup> The Bazetts formula was used to correct QT interval from heart rate because it is the most clinically used method; however, we also report the QTc interval based on Fridericias correction for the cohort 3 in which the drug is associated with significant changes in heart rate.

### Statistics

In cohort 1, we have recorded the standard ECGs and scale ECG in the same condition (sitting position) enabling a direct comparison of the interval measurements between devices (RR and QTc intervals). We used the Bland–Altman method<sup>5</sup> to assess the level of agreement between QTc interval measurements between the two recording technologies. In cohorts 2 and 3, ECGs were recorded using different body position leading to different QTc interval measurements because of the difference in autonomic state (and heart rate). Therefore, we will not compare QTc values in supine and standing recordings between measurements methods, but we will compare the level of variability of these measurements in these different postures (across patients and between replicate

ECGs). The assessment of the QT scale reliability will rely on the intraclass correlation (ICC) computed on the replicated ECGs across the whole recordings of the second cohort consisting of AF patients.<sup>6</sup> Reliability (ICC) is reported as a number between 0 and 100 (in percent), and high reliability (ICC = 100%) means that the difference between the successive measurements are true and do not include measurement errors. The ICC values for standard and scale ECG devices will be compared. These measures of reliability and stability were compared between recording devices and between measurement techniques.

When comparing simultaneous measurement of RR and QT in the healthy cohort, we tested whether the difference between the compared approaches was not statistically different from zero using paired and nonpaired *t*-test or non-parametric Wilcoxon test when appropriate.

## RESULTS

The enrollment period of the study lasted for 5 months spanning between February and June 2015. We enrolled 16 subjects in cohort 1, 54 patients in cohort 2, and 13 patients in cohort 3. Three subjects were withdrawn from the study in cohort 2 for reasons independent from the study.

### Learning Set: Cohort 2

Cohort 2 included 38 males and 13 females ( $58 \pm 18$  vs  $61 \pm 16$  years,  $P = 0.6$ ), 2 of the male subjects were African American while the rest of the cohort were Caucasians.

For the clinical ECGs, the manual QTc measurements could not be done in 3 ECGs of 102 paper tracings (2.9%). Two ECGs (replicate) from the same individual had poor quality signals because these ECG tracings had low-amplitude T wave and QT interval could not be extracted. In the third recording, RR could not be measured. As a note, the commercial machine did not deliver automatic QTc interval measurements in these three ECGs.

Initially, among the 51 subjects and 102 scale ECG recordings recorded in this cohort, 16 recordings (31.3%) did not have either the RR or/and the QT interval available. By tuning in the detection algorithm, we reduced the number of ECGs in which the measurements could not be done to 5 (4.9%). One subject did not have any

ECG with quality high enough to extract the ECG intervals, and three subjects had only one of the two ECGs in which QT and RR could be measured. Therefore, 98% of subjects had at least one successful recording on which the QT and RR could be measured.

Ultimately, the average and standard deviation of heart rate values were  $69 \pm 14$  versus  $78 \pm 17$  bpm ( $P < 0.001$ ) between the clinical ECGs and the scale ECGs, reflecting the changes in body position, that is, supine versus standing. The QTc intervals durations were equal to  $470 \pm 72$  versus  $465 \pm 60$  milliseconds ( $P = 0.74$ ) for the clinical versus scale ECGs, respectively. These results were based on average values from replicated ECGs. The intravariability, intervariability, and the ICC for QTc intervals and heart rate measurements in this learning set were as follows: the most stable results for QTc were obtained for the manual method (95%) while the automatic from the QT scale was equal to 81%. The ICC measures of RR interval were the highest for the QT scale (99%) and slightly lower in standard ECG (97%).

### Validation Set: Cohort 1 and Cohort 3

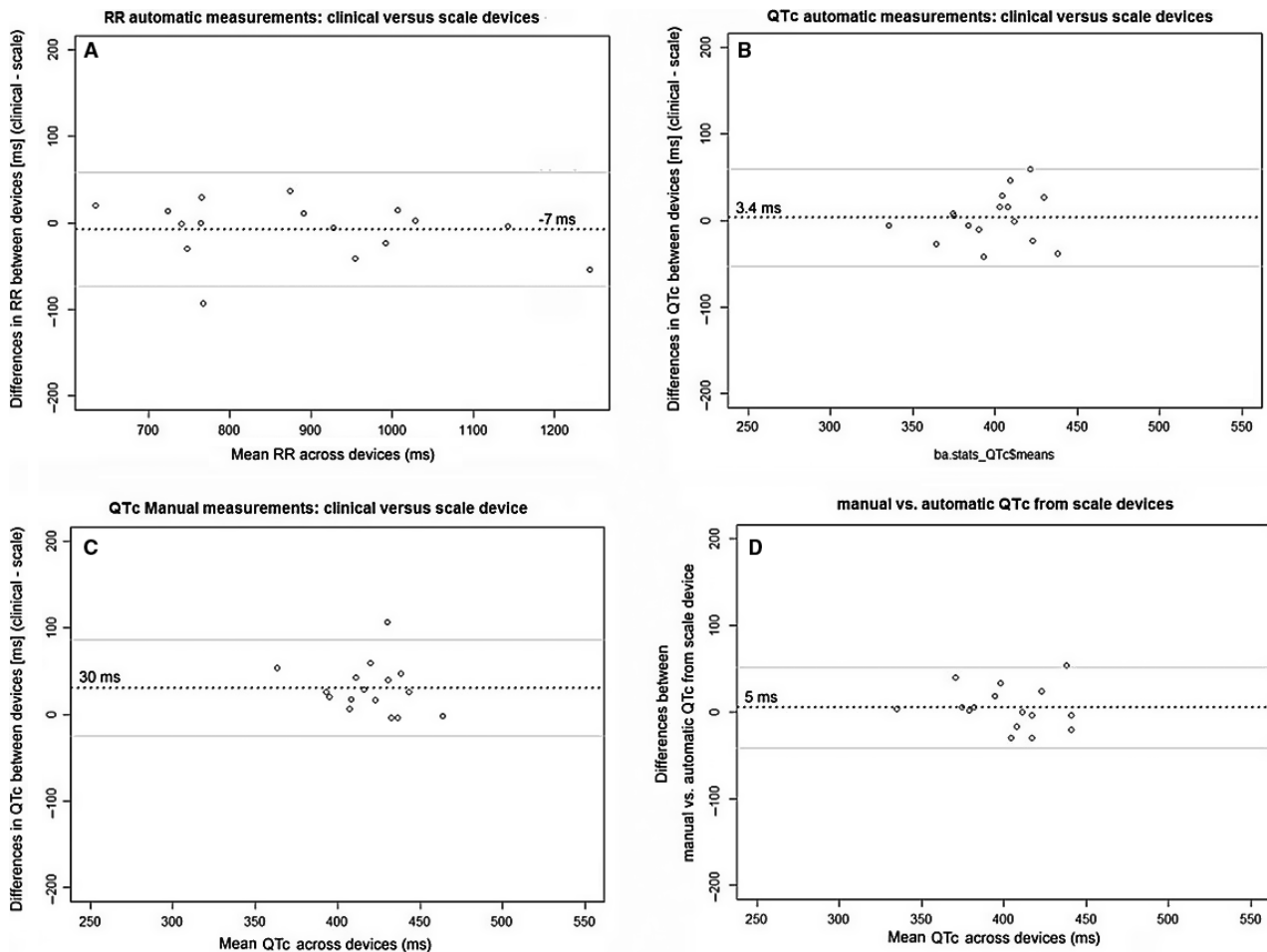
In cohort 1, we enrolled 16 subjects including eight women and eight men ( $32 \pm 8$  vs  $34 \pm 10$  years,  $P = 0.7$ ). All subjects were Caucasian except for one individual: African-American woman. Similar heart rate and QTc were delivered by the scale and the clinical device: paired difference in RR and QTc were  $-7 \pm 34$  milliseconds ( $P = 0.37$ ) and  $3.4 \pm 28.6$  milliseconds ( $P = 0.64$ ), respectively. In Figure 2, we report the Bland–Altman (BA) plots to evaluate the level of agreement between measurement methods and recording devices. Specifically in this figure, the panel A displays the paired comparison between RR interval measurements (fully automatic measurements and mean from all replicates) between the clinical and the scale devices; in panel B, the BA plot shows the differences between automatic QTc measurements from the clinical and scale devices; in panel C, the manual QTc measurements from clinical and scale devices, and finally in Panel D, the manual versus automatic QTc interval from ECGs recorded using the scale device. The only statistically significant difference was found between manual QTc measurements from the

clinical and scale device. When investigating paired differences of QTc interval for manual QTc measured from the signal acquired by the clinical and the scale device, we found that QTc from clinical device was  $30 \pm 28$  milliseconds ( $P = 0.007$ ) longer than from the scale ECG. Importantly, none of the Bland–Altman plot shows any trend toward a biased agreement between methods.

In cohort 3, we enrolled 13 cardiac patients suffering from atrial fibrillation (AF), nine men and four women ( $64 \pm 10$  vs  $63 \pm 11$  years,  $P = 0.93$ ), all Caucasian. One of the subjects was withdrawn after refusing to participate post enrollment. Among the 12 remaining subjects, eight subjects had three recordings sessions (two standard ECGs and two QT scale measurements). One patient had withdrawn after the first recording session. One subject was discharged before the last dose of dofetilide, and therefore, only the two first sessions were recorded. One of the subjects had only one recording session because of a failure of the QT scale hardware, which led to stopping the recording protocol. The technical problem was troubleshooted and an internal fuse failure was fixed. Three recordings from the clinical ECG system did not work properly, and the quality of the recordings was so poor that the interpretation, the QT, and the RR intervals were either unavailable or out of normal range (these were manually checked).

We report in Table 1 the heart rate (HR) measurements from the validation set for the baseline, after the first dose, and after the last dose of dofetilide between the clinical ECG and scale ECGs. There was no statistical difference between the values despite a slightly higher HR reported during the scale measurements that were expected for different body position ( $82 \pm 20$  vs  $74 \pm 19$  bpm,  $P = 0.13$ , when merging all periods). The metrics of stability of RR measurements (ICC, intrareplicates, and intersubjects) are reported in Table 2. The average ICC across the three recordings periods (baseline, after the first dose, and after the last dose) for HR is 97% for both the QT scale and the clinical device (clinical ECG).

Table 1A reports the heart rate measurements. The QTc values for automatic and manual reading from the scale ECGs were  $471 \pm 58$  versus  $489 \pm 50$  milliseconds ( $P = 0.23$ ), respectively, across all periods. The average and standard



**Figure 2.** Bland–Altman plots describing the level of agreement for the RR and QTc interval measurements across measurement methods and recordings devices. Bland–Altman plots for: (A) the automatic RR intervals between clinical and scale devices; (B) the automatic QTc between clinical and scale devices; (C) the manual QTc between the clinical and scale devices; and (D) the manual and automatic QTc from the scale device.

deviation of QTc values per periods are reported in Table 1B. Dofetilide lowered heart rate and increased QTc interval durations. After the first dose of dofetilide, the QTc increased when using the Fridericias correction: +23 and +12 milliseconds for the manual and automatic method, respectively; while QTc intervals is not strongly affected by the drug when using the Bazetts formula (+8 and –2 milliseconds).

In Table 2, we report the ICC (reliability) for HR and QTc. For the clinical ECG machine, the ICC for the QTc is 91% for the manual methods, while for the scale ECG, the ICC are 60% and 80% for the manual and automatic methods, respectively. The values of ICC are summarized in Figure 3 for RR and QTc measurement across measurement methods.

The clinical impact of the higher variability of short-term QTc measurement in the clinical realm is not expected to be significant in the general population. However, in patients with prolonged QTc, an increased variability may lead to increase the number of false results or low sensitivity and specificity. To illustrate this limitation, we computed the percentage of replicated ECGs showing inconsistent results when using specific limits for QTc values to detect the presence of an abnormal QTc interval duration, such as QTc > 500 milliseconds. We varied this threshold from 450 to 550 milliseconds and computed the percentage of session during which replicated ECGs are inconsistent. We report this percentage from the learning set of data in Figure 4.

**Table 1.** Heart Rate and QTc Measurements in the Cohort 3 (mean ± SD)

A	HR (bpm)	
	Clinical ECG	Scale ECG
Baseline	84 ± 21	94 ± 22
After first dose	67 ± 12	78 ± 17
After last dose	62 ± 10	71 ± 13

B (Scale ECG)	QTc (milliseconds) (Bazett)		QTc (milliseconds) (Fridericia)	
	Manual	Automatic	Manual	Automatic
Baseline	487 ± 58	481 ± 63	453 ± 42	447 ± 44
After first dose	495 ± 53	479 ± 62	476 ± 51	459 ± 50
After last dose	485 ± 41	452 ± 50	473 ± 39	440 ± 42

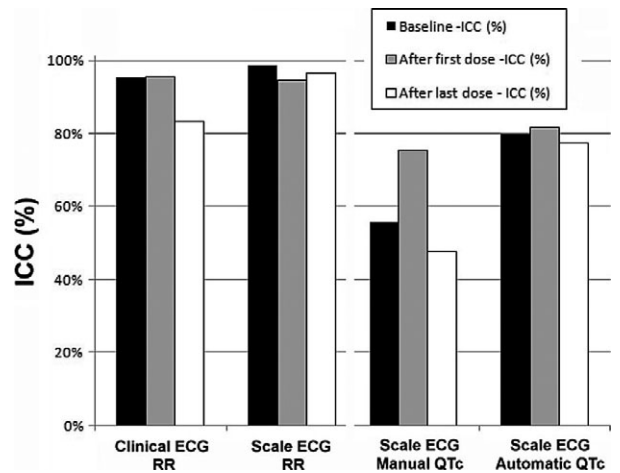
None of the comparison between values of heart rate from the clinical and the scale average was statistically significant. None of the comparison between manual and automatic average values was statistically significant.

**Table 2.** Intraclass Coefficients and Intravariability/Intervariability of QTc Interval and Heart Rate in the Validation Cohort (Cohort 3)

ICC (n)	HR		QTc	
	Device ECG	Scale ECG	Scale ECG Manual	Scale ECG Automatic
Baseline	99 (12)	96 (11)	56 (11)	80 (11)
After first dose	95 (10)	99 (9)	75 (9)	82 (9)
After last dose	96 (8)	96 (9)	48 (9)	77 (9)

ICC is expressed in percent, and the number between parenthesis indicates the number of subjects in each group of measurements.

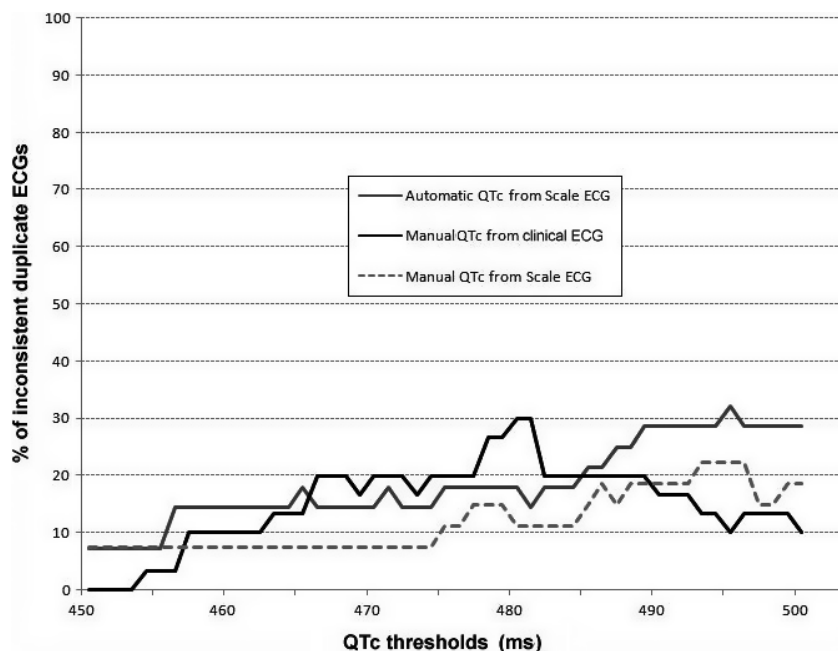
As expected, the intrareplicate variability is lower than the intersubject one for all methods. Specifically, the manual QTc measurement from the scale had the worse stability (low reliability) in the set of ECGs recorded after the last dose. These were explained by abnormal T wave morphology (very flat amplitude) across replicate ECGs. In Figure 5, we report examples of three ECG tracings from cohorts 2 and 3 with good-quality measurements and one tracing with high variability from the scale. In such cases, the algorithm behaves very consistently but manual measurements are very variable. In Table 3, we report the HR and QTc values per replicate ECGs; there were no statistical differences between first (M1) and second (M2) recording.



**Figure 3.** Intra-class coefficient (ICC) of the QTc and RR interval measurements computed for the three sets of data from cohort 3, i.e., at baseline after the first dose of dofetilide, and after the last dose of dofetilide. ICCs for the automatic heart rate measurements from a clinical device and from the scale ECGs are on the right side, and the manual and automatic QTc intervals from the ECG recorded with the scale device are reported on the left side.

## DISCUSSION

In this work, we propose to integrate an ECG recorder into a weight scale and to test its ability to deliver reliable QTc interval measurements to reduce the constraints described above. We implemented an investigational study in which the QT scale, a weight scale embedding a 3-lead ECG recorder, was used in cardiac patients to



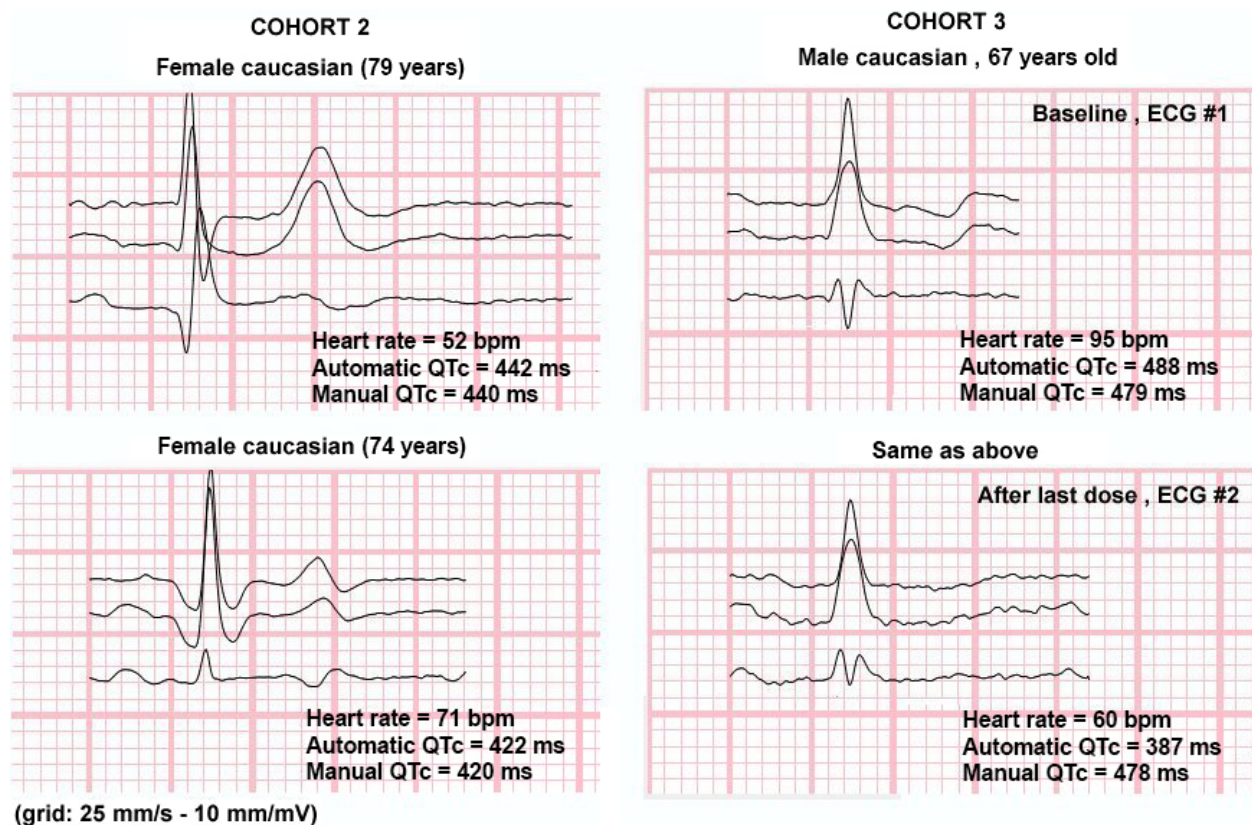
**Figure 4.** The three curves present the percentage of inconsistent findings when the QTc interval is used to identify the presence of abnormal QTc using a threshold varying from 450 to 500 milliseconds. Hundred percent means that none of the replicate ECGs are consistently showing values below the selected threshold, while 0% means that all replicate ECGs are consistently showing values below the selected threshold. The darker curve presents the performance of a manual reader using standard 12-lead ECG tracing, while the dotted gray curve the performance by the same reader using the electrocardiogram from the QT scale. Finally, the continuous gray curve is the performance of the automatic measurement from the QT scale ECG signals.

measure heart rate and QT intervals. The scale device was built by a group from Technical University of Catalonia (Barcelona, Spain) (ESF, OC, RPA) by simplifying a previous design,<sup>7</sup> while the University of Rochester (JPC, XN) designed and integrated a software interface delivering the measurements of the RR and QT intervals from the ECG signal acquired with the scale. The QT measurement methods were optimized using visual adjudication of the end of the T wave with a set of recordings acquired in cardiac patients. Then, we evaluated in an independent set of ECGs recorded in cardiac patients with AF exposed to QT-prolonging drug (dofetilide) and in a set of presumed healthy subjects. The QT scale devices generated slightly lower stability than standard 12-lead ECGs (ICC: 91% vs 80%) for QTc interval measurements and equivalent stability for heart rate measurements.

The QTc prolongation on the surface electrocardiogram is an independent risk factor for sudden cardiac death in the general population,<sup>8,9</sup> in infants during the first week of life (sudden infant

death syndrome),<sup>10</sup> and it is a significant independent marker of risk for cardiac events in the acquired<sup>11</sup> and inherited<sup>12</sup> forms of the long QT syndrome (LQTS). In critical care units, the QTc monitoring is recommended to identify these patients with risk of torsades de pointes.<sup>13,14</sup> In the general population, the prevalence of the congenital LQTS is estimated to 1 in 2000–2500 live birth,<sup>15</sup> while the prevalence of drug-induced QTc prolongation is expected to be much larger because of the large families of drugs associated with risk of QTc prolongation which include antiarrhythmics, antihistamines, antimicrobials, antidepressants, and neuroleptics, among others. Regulatory bodies have regulated the access to the market of QT-prolonging drugs,<sup>16</sup> but many drugs are still prescribed by health professional that bear the risk for adverse events linked to QTc prolongation such as torsades de pointes either by themselves and/or by interaction with other drugs, and/or by patients intrinsic susceptibility (genetic variants). The pool of patients exposed to these potential QT-prolonging drugs is





**Figure 5.** The ECG tracings from the QT scale: in cohort 2 (top and bottom left) for good-quality signals where manual and automatic QTc measurements are close, and before and after dofetilide in cohort 3 (top and bottom right, respectively) for the same subject. In this latter example, the drug has been associated with strong changes in T wave morphology and especially lowering of the T wave amplitude where the identification of the end of the T wave becomes challenging.

**Table 3.** Heart Rate and QTc Measurements (Mean  $\pm$  SD) per Replicate ECGs

Cohort 3 (Validation)	HR (bpm)		QTc (milliseconds)	
	Clinical ECG Automatic	Scale ECG Automatic	Scale ECG	
			Manual	Automatic
M1	74 $\pm$ 18 (29)	81 $\pm$ 20 (28)	478 $\pm$ 55 (27)	461 $\pm$ 64 (28)
M2	73 $\pm$ 19 (30)	83 $\pm$ 21 (29)	497 $\pm$ 56 (30)	483 $\pm$ 65 (29)
P-value*	0.94	0.69	0.21	0.19

\*Test if the averaged delta values are significantly different from 0 between replicate ECGs. The numbers between parenthesis report the number of ECGs used to compute the statistics.

large, but the number of patients developing harmful QTc interval prolongation is expected to be low. This explains partially why the ECG screening for QTc prolongation is not routinely implemented in the general population but also in more specific groups of subjects such as infants despite the fact that cost-effectiveness of

screening was studied and reported to be acceptable.<sup>10</sup>

One of the major costs associated with QT screening resides in the time and resources needed to obtain a QT/QTc interval measurement. These resources are multiple: access to a specific and dedicated device (ECG recorder), a

competent and trained ECG operator, the time for patients skin preparation and electrode placement, and time for recording and conducting interpretation. Therefore, the integration cost of QTc screening into any health care framework is expected to be significant.

The major challenge in using the scale ECG was to ensure a good quality of the ECG signal. In the learning cohort, two subjects had ECG signals of very low quality in which neither the QT interval nor the heart rate could be measured. This lack of signal quality was explained by inappropriate contact between the device sensors and the limbs of the patients, specifically the feet. The next version of the device will be revised to integrate sensors that have larger contact surface. Furthermore, the patient may have difficulty to stand still on the scale specifically those patients who are obese. Movement during the recording generated substantial noise that influenced the stability of the recordings (this was not quantified but observed during the recording periods).

To conclude, we believe the proposed concept is interesting because it would enable an easy integration of QTc measurement to any clinical, physical health, or even home routines. This concept benefits from three major characteristics: (i) it could deliver QTc measurement without considering a dedicated equipment, (ii) it is easily integrated by being combined with standard health routine (i.e., weight measurements), and (iii) it does not require ECG-trained individual to record the surface ECG and measure the QT/QTc interval.

## LIMITATIONS

We believe that the differences in QTc measurements between the two recordings systems would be driven by differences in body position (seating, standing, and supine) and number of leads available (limb leads vs standard 12-lead system). Therefore, the assessment of the QT scale value was based on the ICC values providing insights into QTc measurement stability and repeatability in cohort 3. In cohort 1, standard ECG and QT scale ECGs were recorded simultaneously enabling a direct comparison of heart rate and QTc values.

One would note that the lower stability for the period on drug may be due to the lower heart

rate. Since the scale algorithm depends on a signal-averaging technique from 1-minute recording period, in patients with lower heart rate, the signal contains a lower number of beats and therefore lower signal-to-noise values. This limitation may be avoided in the future by recordings for a specific number of beats.

Finally, the device deserves to be tested thoroughly in patients with definitive drug-induced long QT syndrome, specifically in these patients treated with QT-prolonging drugs with reverse use dependency effect.<sup>17</sup> We propose to acquire ECG in standing position; therefore, the QTc prolonging effect may be masked due to the increased heart rate associated with a standing position. More investigation is needed to elucidate the effect of body position.

## CONCLUSIONS

We investigated the use of a weight scale for integrating QT intervals in clinical routine without involving standard 12-lead ECG and therefore minimizing the time and cost of getting a valuable electrocardiographic measurement. The device shows reliable and stable assessment of heart rate and QTc intervals. The design of the device is to be improved and evaluated in a larger cohort of patients.

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