# Measurement of QT Interval and Duration of the QRS Complex at Different ECG Sampling Rates

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## Abstract

*The precise measurement of $QT$ interval and $QRS$ complex duration is important to characterize the electrical cardiac activity of the surface $ECG$. Variations of these intervals were evaluated when $ECG$ sampling rate changes. The $ECG$ recordings used in this study (n = 78) were obtained from a combination of pharmacological blockage and postural changes. The $ECG$ recordings were originally sampled at 500 Hz, and then were down-sampled by intervals of 25 Hz until the minimum sampling rate of 75 Hz. In all cases the down-sampling was implemented using cubic spline interpolation. The $QRS$ complex duration, $RR$ and $QT$ intervals for each subject, condition and sampling rate were measured. The $QT$ interval was corrected using two different techniques: Bazzett and individualized $QT$ corrections. The effect of the sampling rate was modeled with an exponential decay function, which was used later to measure where the exponential reaches an asymptotic value (at $5\tau$). The $5\tau$ value for uncorrected $QT$ was at 290 Hz, corrected $QT$ with Bazzett was at 303 Hz, and corrected $QT$ with Individual method was at 253 Hz, finally $QRS$ complex duration was at 297 Hz. An overestimation of the $QT$ interval and $QRS$ complex duration was observed when decreasing the sampling rate below 300 Hz.*

## 1. Introduction

The surface $ECG$ analysis is widely used for the diagnostic of cardiac diseases. The $ECG$ is a noninvasive technique that allows the visualization of the heart's electrical activity. The changes in duration of the $QT$ interval are related to certain pathologies, and with the effects of diverse drugs. On the other hand, the duration of $QRS$ complex also gives information about the status of the myocardial conduction system. All this rise the necessity of making precise measurements of these intervals of the $ECG$ [1] [2].

The measurements on the $ECG$ are mostly defined by the characteristic extrema, amplitudes, wave morphologies and intervals of time between extrema points (Figure 1).

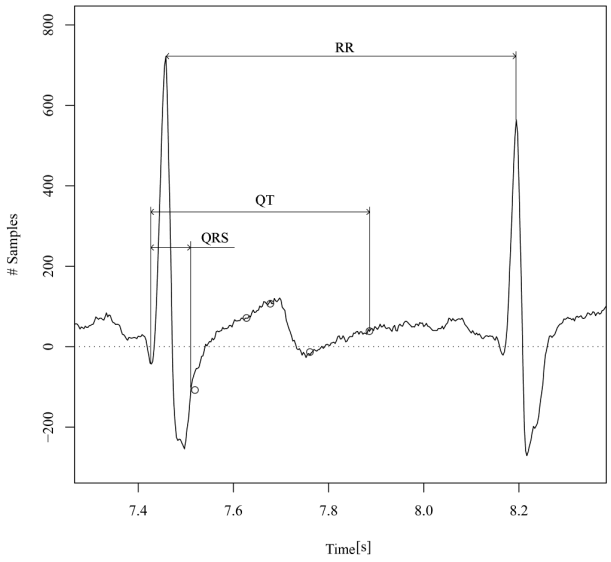


Figure 1. Definition of $RR$, $QT$ and $QRS$ complex in an ECG beat.

In the present study the $QT$ interval and duration of the $QRS$ complex were measured when the autonomic nervous system was blocked with a combination of drugs and postural changes.

Administration of atropine and propranolol was used to block sympathetic and vagal systems respectively, while subjects were in standing and supine position. This pharmacological and postural combination is useful to explore the $QT$ interval correction techniques within a wide range of HR variations [3].

An incorrect choice of the sampling rate ($F_s$) may introduce errors when the fiducial points of the $ECG$ are measured, and therefore the intervals or segments between

these points.

The aim of the present study was to investigate the effects of the sampling rate in the measurement of $QT$ interval and of $QRS$ complex duration.

## 2. Methods

### 2.1. Experimental protocol

The database used in this work proceed from a previous work [3] where the regulation mechanism of the autonomic nervous system was studied. Electrocardiogram recordings were made on 13 adult subjects (age between 19 and 39, median 21 years). Those recordings were made during autonomic nervous system blockade by using pharmacological (atropine, propranolol) and postural (supine, standing) combinations.

The ECG recordings were made of the following way: a) all subjects were measured in supine control position ($SUC$) then were moved to the standing control position ($STC$) and measured after 5 minutes for hemodynamic equilibration; b) then all subjects were returned to the supine position and given either atropine (0.03 mg/kg, n=7) or propranolol (0.2 mg/kg, n=6) reaching $SUA$ and $SUP$ condition respectively, both groups were measured after 10 minutes for equilibration; c) then all subjects were moved to the standing position, and after 5 minutes for hemodynamic equilibration STA and STP conditions were reached and measured respectively ; and d) finally subjects in $SUA$ and $STA$ were supplied propranolol, and subjects in $SUP$ and $STP$ were supplied atropine, in both cases this subjects reached total autonomic blockade ($SUB$ and $STB$), and measured after 5 minutes. The database used in this work contains a total of 78 $ECG$ recordings of 7 minutes each [3] [4].

### 2.2. Acquisition and signal processing

The $ECG$ recordings were sampled originally at a frequency of 500 Hz, then were down-sampled in steps of 25 Hz until a minimum frequency of 75 Hz, therefore were obtained additional recordings at $F_s$ of 475, 450, 425, 400, 375, 350, 325, 300, 275, 250, 225, 200, 175, 150, 125, 100 and 75 Hz.

In all cases, before changing the sampling frequency (resampling) an anti-alias filter was applied, defining the band of pass frequency ($F_{pass}$), and a cutoff frequency ($F_{stop}$) equal to half of the sampling rate. The specifications of the anti-alias filter were the following: a) equiripple FIR filter with a stop band of 40 $dB$, b) bandpass ripple of 1 $dB$, and c) $F_{pass}$ = 80% $F_{stop}$. The resampling was implemented with a cubic spline interpolation method [5].

The measurements of extrema points were made automatically with a program developed in R language [6]. The automatic measurement of the $QT$ interval and the $QRS$ complex, was preceded by the detection of the following extrema points: Q wave ($Q$), S wave ($S$) and end of T wave ($T_e$). The detection algorithm managed the presence of both monophasic and biphasic T waves, and either $PQ$ or $TP$ segments may be used as the isoelectric baseline.

To ensure that the algorithms were applied correctly according to the T wave morphology and isoelectric baseline, a qualified observer classified the $ECG$ recordings, performing a randomly inspection of two minutes for each $ECG$ recording.

Once the detection of all the extrema points were completed, the $QT$ interval and $QRS$ complex were calculated. Only the heart beats with proper signal to noise ratio (SNR) and $RR_{[i]} > 450\ msec$ (equal to a $HR < 133\ bpm$) and $RR_{[i]} > 0.75 * RR_{[i-1]}$ were take it into account.

Since some $ECG$ recordings had high frequency noise, they were smoothed with a moving average filter (low pass, cutoff frequency of 10 Hz, and 17 taps). This filter was designed to preserve the $T$ and $P$ waves [7]. Isoelectric baseline movement was removed from the $ECG$ after interpolating this movement with cubic spline method [5]. This procedure was repeated for all $F_s$.

Finally, the $QT$ interval was corrected ($QT_c$) by two correction methods: Bazzett ($QT_{cB}$) [8] and Individual ($QT_{cI}$) [9]. Bazzett's correction uses the following parabolic expression:

$$QT_c = \frac{QT}{RR^{\alpha}}\ with\ \alpha = 0.5 \tag{1}$$

In the Bazzett's correction formula $RR$ is in seconds, and $\alpha$ is fixed at 0.5. In the case of Individual correction the $\alpha$ value is calculated for each recording using a correlation model between $QT$ and $RR$. This method uses the $\alpha$ value which correspond to the minimum value of the coefficient of determination ($r^2$) between $QT$ and $RR$. The figure 2 shows the diagram of the individual $QT$ correction.

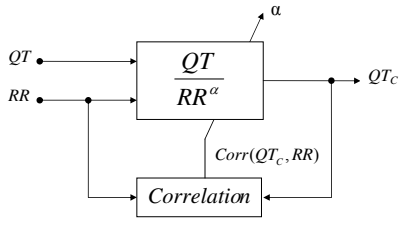


Figure 2. Diagram of the individual $QT$ correction.

## 2.3. Modelization of sampling frequency changes

The effect of the sampling rate was modeled with an exponential decay function:

$$Y(F_s) = y_0 + a.e^{-F_s/\tau} \quad (2)$$

From this model, the minimum sampling rate was calculated. At this frequency the exponential function reaches the asymptotic value, this value is reached at a frequency of approximately five times $\tau$ ($5\tau$).

## 2.4. Statistical analysis

Analysis of variance (ANOVA) test were made for all variables under study, followed by a Bonferroni's post-hoc for multiple tests correction. All the statistical analysis were performed using the R language [6].

# 3. Results

The results are expressed as mean $\pm$ tandard deviation. This value was obtained averaging the mean values for each $ECG$ recording. Table 1 summarizes the results.

The RR was statistically significant different in SUA ($P < 0.05$) and SUB ($P < 0.001$) respect to control. On the other hand, differences statistically significant were found in STA ($P < 0.05$), STP ($P < 0.005$) and STB ($P = 0.033$) respect to control. The figures 3, 4, 5 and 6 show uncorrected mean $QT$, mean $QT_{cB}$ by Bazzett and mean $QT_{cI}$ by Individual correction. The exponential model is represented in solid lines. Mean value and standard deviation at both sides. The dashed lines correspond to the horizontal asymptotes, and each point corresponds to the mean of the variable under study. Vertical lines represent the standard error of each mean.

The $5\tau$ frequency was at 290 Hz for $QT$, at 303 Hz for $QT_{cB}$, at 253 Hz for $QT_{cI}$, and at 297 Hz for $QRS$.

The measurement at 500 and 75 Hz was 408 and 423 ms for $QT$, 469 and 485 ms for $QT_{cB}$, 447 and 453 ms for $QT_{cI}$, and finally 116 to 132 ms for $QRS$ complex duration.

# 4. Discussion

The present study used a database where a wide variation range of $RR$ and $QT$ intervals were obtained using combinations of pharmacological and postural procedures. The recordings in this database allowed the analysis of $RR$ and $QT$ intervals in a full range of physiological situations, therefore it was possible to appreciate the effect of two $QT$ interval correction methods. Finally, it was verified that sampling rate affects the measurements of $QT$ interval and duration of $QRS$ complex, in both cases these variables were overestimated at $ECG$ sampling rates below 300 Hz.

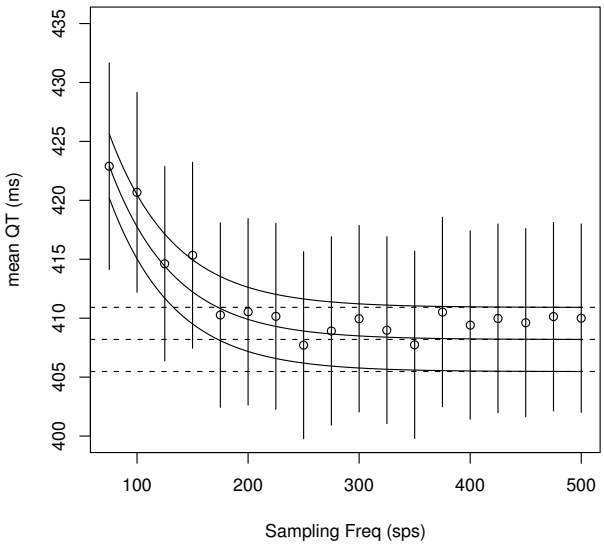


Figure 3. Mean $QT$ model versus $F_s$.

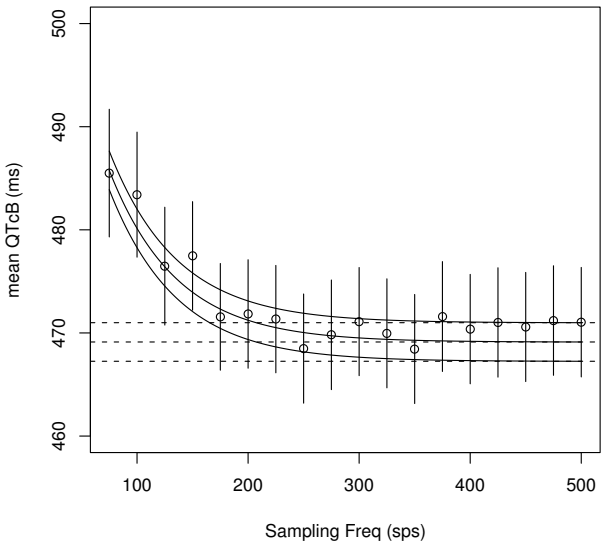


Figure 4. Mean $QT_{cB}$ model against $F_s$.


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Table 1. Supine position, results in milliseconds as Mean ± Standard Deviation.

| $Variable$ | $Control$ | $Atropine$ | $Propranolol$ | $Both$ |
|---|---|---|---|---|
| $RR_MSu$ | 878.9±112.0 | 604.4±139.2‡ | 1038.7±144.8* | 655.4±62.7‡ |
| $RR_MSt$ | 738.8±96.3 | 502.4±56.9‡ | 912.2±88.1‡ | 645.34±50.1* |
| $RR_{SD}Su$ | 76.3±28.1 | 19±26.2‡ | 84.2±55.2 | 11.5±7.7‡ |
| $RR_{SD}St$ | 72.4±37.9 | 15.3±9.1‡ | 67.2±54.3 | 11.8±4.2* |

* ($P < 0.05$); † ($P < 0.005$); ‡ ($P < 0.0005$)

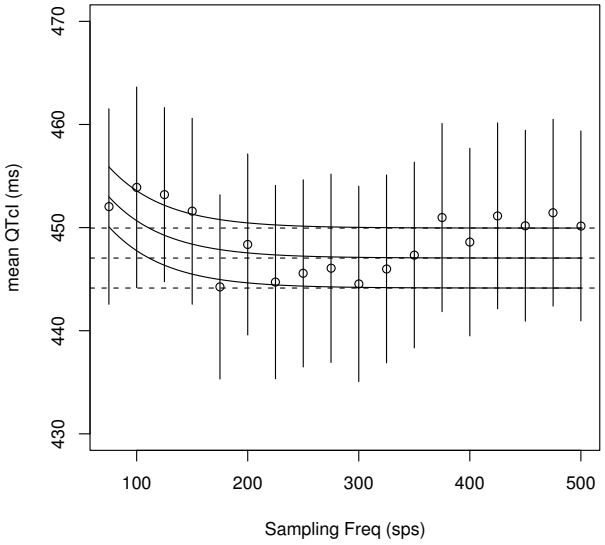


Figure 5. Mean $QT_{cI}$ model against $F_s$.

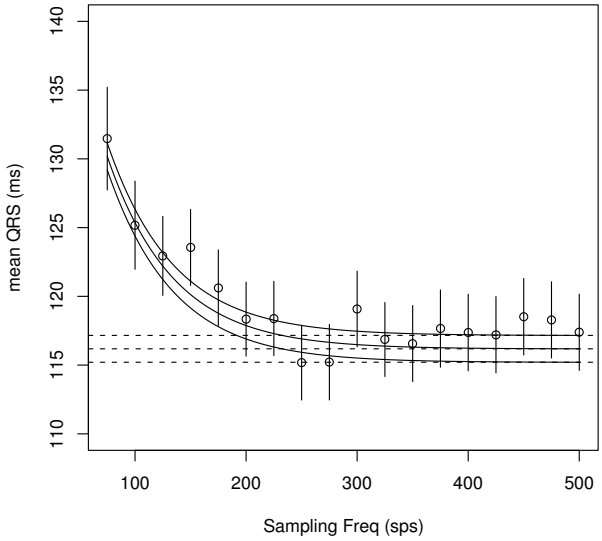


Figure 6. Mean $QRS$ complex model against $F_s$.

de Zaragoza, Spain.

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