Fully Automated Method for QT Interval Measurement in ECG

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Abstract

Fully automated method for QT interval measurement is presented. It includes ours: QRS detection algorithm and ECG signals preprocessing allowing suppression of power-line interference, electromyographic noise and baseline drift guaranteeing accurate preservation of the QRS-onset and T-end locality. Representative heart beat is automatically selected at the smallest difference between two consecutive RR intervals. Our method for automatic detection of QRS-onset and T-end is based on the minimum value of the angle between two segments having a common mid point and equal lengths of 10 ms. The minimum of the angle is searched in defined time intervals delineated separately for the Q and T.

The method is developed with a feedback to published experts' markings for Q and T. The mean and standard deviations of the QT differences between our method and the experts' markings are 3.86±12.52 ms. The score 25.19 for the Challenge 2006 is the second best in Division 3

1. Introduction

In comparison with manual methods, the automated ones offer advantages in terms of absolute repeatability of measurements, immunity from errors related to observer fatigue, lapses of attention, as well as efficiency and cost that permit either more extensive and rigorous testing for the same cost as manual methods, or more rapid testing at lower cost [1].

The absolute prolongation and the dynamic changes in the QT interval are of great importance to the prognosis of Torsade de pointes, ventricular tachycardia, flutter or fibrillation, syncope, seizures, and sudden cardiac death. An undesirable property of some anti- and non-antiarrhythmic drugs is their ability to delay cardiac repolarization [2].

The QT dispersion defined as the difference between the longest and the shortest QT intervals or as the standard deviation of the QT duration in the 12-lead ECG [3], currently is the subject of significant interest. Several years ago Campbell [4] enthusiastically called it the 'electrophysiological Holy Grail'. The number of studies indexed in the Medline on QT dispersion is more than 1200 since its description in 1990.

Some authors are poles apart in their views on the QT measurement, because of the complexities of assessment and interpretation [5], asserting that the QT dispersion results mainly from variations in the T loop morphology and the error of QT measurement [6].

For that reason the question: 'Can the QT interval be measured by fully automated methods with accuracy acceptable for clinical evaluations?', forwarded by the PhysioNet/Computers in Cardiology Challenge, 2006 [1], is of high clinical interest.

The 'classical' problem of quantitative electrocardiography has been approached by the Common Standards of Electrocardiography Working Group (CSEWG) [7,8]. An international project consisting of active participants from 20 Institutions of the EC was initiated to overcome the lack of standards, agreement on wave definitions and measuring protocol equalization [9]. A reference library was therefore established through a comprehensive, interactive review process that was performed by cardiologists on highly amplified ECG tracings. The CSEWG used repeated assessments in 4 rounds: the first 3 to correct the inter-observers differences and the 4th to correct the common referees' median with respect to program derived one. Computer programs tested against the CSEWG [8-10] or another manually created reference database [11,12] had slightly greater deviations than the inter-observers measurements.

A set of manually measured QT intervals for the PTB Diagnostic ECG Database recordings was created [13] to be used as reference and feedback to the development of automated methods for the QT interval measurements, as well as for Q onsets and T ends markings. To obtain closer to the median results, the referees' markings were performed in 3 rounds following all the CSEWG recommendations.

Influence of noise on wave boundary recognition by ECG measurement programs has long ago been investigated [14] Increasing levels of EMG noise and power-line interference shifted the wave onsets and offsets of most programs outward. Erroneous estimations of the Q and T were observed even in the cardiologists' expert markings [13].

Under the terms of the Challenge 2006 we are presenting a fully automated method for QT interval measurement, including our QRS detection algorithm [15], and ECG signals preprocessing allowing suppression of power-line interference, electromyographic (EMG) noise and baseline drift according to our previously published investigations guaranteeing accurate preservation of the QRS-onset [11], and T-end locality [12]. Representative heart beat is automatically selected at the smallest difference between two consecutive RR intervals.

2. PTB Diagnostic ECG Database

The data to be used for the challenge are the 549 recordings of the PTB Diagnostic ECG Database, which was contributed to PhysioNet in September 2004 by its creators Michael Oeff, Hans Koch, Ralf Bousseljot, and Dieter Kreiseler [16,17].

Each of the 549th recordings contains 15 simultaneously acquired signals: the conventional 12 leads and the 3 Frank (XYZ) leads. All of them are digitized at 1000 samples per second, with 16 bit resolution over a range of ±16.384 mV. The recordings come from 294 subjects (each represented with one to five recordings) within a broad range both for age and diagnosis. About 20% of the subjects are healthy controls. The recordings are typically about two minutes in length, with a small number of shorter recordings (none less than 30 seconds).

Each ECG recording is accompanied by a detailed clinical summary, including age, gender, diagnosis, and where applicable, data on medical history, medication and interventions, coronary artery pathology, ventriculography, echocardiography, and hemodynamics. Diagnostic classes of the subjects as: Coronary artery diseases, Heart failure, Hypertensive heart disease, Rhythm disturbances, etc., are also described.

3. Methods

The fully automated method was developed following the Challenge 2006 requirements [1]:

- Estimation of the QRS-onset and T-end locations (further called just Q and T) must be performed on lead II.
- Representative beat must be chosen automatically in such a way as not to be ectopic, and to be close to the dominant beat with the least possible shift, noise, and artefact.

3.1. QRS detection

We apply our own algorithm for real time electrocardiogram QRS detection using combined adaptive thresholding [15]. The algorithm is self-adjusting to the thresholds and weighting constants, regardless of resolution and sampling frequency used. It operates with any number of ECG leads, self-synchronizes to QRS beat slopes, and adapts to beat-to-beat intervals.

3.2. Automatic selection of a representative beat

All RR intervals in the recording are measured and representative beat is chosen at the place of the minimum difference between two successive RRs.

3.3. Signal preprocessing

The ECG signals are preprocessed allowing suppression of power-line interference, EMG noise and baseline drift according to our previously published investigations guaranteeing accurate preservation of the QRS-onset and T-end locality [11,12]:

- Moving averaging of samples in one period of the power-line interference. This filter is meant to eliminate the power-line interference. Its frequency response is having a first zero at the interference frequency 50 Hz (60 Hz);
- A smoothing procedure for EMG noise suppression is applied [12,18] It makes use of the least squares approximation method, applied for defining the weighting coefficients. The mathematical description of the process is:

$$Y_i = \frac{1}{N} \sum_{j=-n}^{j=n} C_j X_{i+j}$$

Y and ***X*** represent the signal after and before approximation respectively, ***n*** is the length of the approximation interval at both sides of a sample. C_j are weighted approximation coefficients, and ***N*** is a normalization coefficient. The procedure is applied on ***2n+1*** samples. We are working with approximation interval of 31 ms. The approximation coefficients are:

$$Cj = 3n^2+3n-1-5j^2,$$

and the normalization coefficient is:

$$N = \frac{(2n+1)(4n^2+4n-3)}{3}$$

- High-pass recursive filter for drift suppression [19]. The phase characteristic of this filter is constant and the phase distortions introduced in forward time direction are cancelled by a second-pass backward application. The high-pass recursive filter is given by the formula:

$$Y_n = C_1(X_n-X_{n-1})+C_2Y_{n-1},$$

where Y_n is the filtered samples sequent, X_n is the samples sequent of the original signal and ***n*** is the consecutive number of samples. The constants C_1 и C_2

are calculated by the formulae:

$$C_1 = \frac{1}{1+\tan(Fc\pi T)} \qquad C_2 = \frac{1-\tan(Fc\pi T)}{1+\tan(Fc\pi T)},$$

where T is the sampling period and $Fc=0.64$ Hz is the chosen cut-off frequency.

3.4. Delineation of the time interval for QRS-onset search

An 'isoelectric' (flat or of low slope) segment is searched in the interval from the biggest peak of the complex (QRS_P, Fig. 1) to 120 ms backwards on the time axis. The segment is found if all successive differences in 20 ms interval between adjacent samples are less than a preset value Crit and the difference between the end-samples of the 20 ms interval is less than 4*Crit. The value of the Crit is dependent to the QRS magnitude:

Crit = 0.02(maxQRS - minQRS).

The leftmost sample of this segment (Q_L, Fig. 1) is set as the leftmost point of the searched time interval.

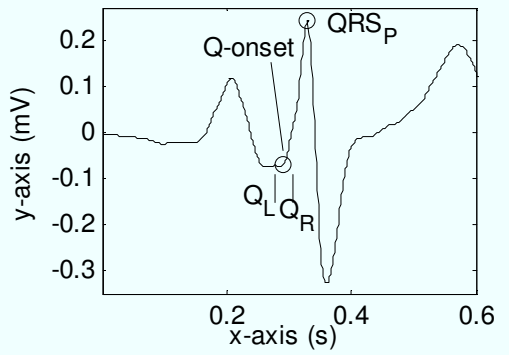

Figure 1. Automatic detection of the Q-onset

The rightmost point of the searched interval (Q_R) is found if a peak or a slope (whichever occurs first) is detected to the right Q_L. Looking for a peak we analyze 3 samples separated by 10 ms. Differences between the middle and the two adjacent ones are made. A peak is found if both differences have same sign and if they are greater than 3*Crit. Detection of a slope is done by analisis of 9 samples, separated by 2 ms. Differences between successive samples are formed. A slope is found if the 8 differences have same sign and their absolute values are greater than 4*Crit. The midpoint of the slope or the peak is set as the rightmost point of the searched interval.

3.5. Delineation of the time interval for T-wave end search

QRS-offset point (J, Fig. 2) is searched to the right of the QRS_P, repeating the described above criteria for Q_L search.

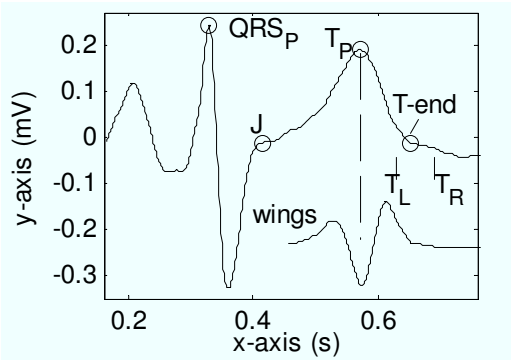

Figure 2. Automatic detection of the T-end

Two adjacent segments forming 'wings' are defined, each segment being of 40 ms length:

$$W_1 = D_{i-40ms} - D_i \qquad W_2 = D_i - D_{i+40ms}$$

where D are the corresponding signal samples.

The 'wings' function ($W=W_1*W_2$) in the interval from J to $J+QTc-100$ ms *is* shown in Fig. 2 (lower trace). QTc is calculated by the well known equation of Bazett. The minimum of 'wings' corresponds to the T-wave peak T_p, no matter if the T-wave has a positive or negative direction.

The steepest slope is searched as a maximum of the W in the interval from T_p to $T_p+QTc/5$.

The right sample of the search interval T_R (Fig. 2) is sought as a minimum of the W in the interval from the point of the steepest slope to $T_p+QTc/5$.

The left sample of the search interval T_L (Fig. 2) is obtained as a point where the amplitude of the T-wave is $0.8(T_p-T_R)$.

3.6. QRS-onset and T-wave end detection

Our method for automatic detection of QRS-onset and T-end (Fig. 1 and Fig. 2) is based on the minimum value of the angle between two segments having a common mid point and equal lengths of 10 ms. The minimum of the angle is searched in the defined time intervals delineated separately for the QRS-onset and T-end.

4. Results

The Challenge 2006 participation in Divisions 2 and 3 [1] requires measurements of at least 95% of the recordings. But our preliminary investigation indicated that no T-wave in Lead II can be observed or its amplitude is less than 0.03 mV in 11.3% of all the recordings. We exercised two methods of approach in such cases: (i) the Bazett's equation for calculating of the corrected QTc interval and (ii) localization of the search interval in the precordial lead V2, followed by T measurement in lead II. We achieved better results in the second case.

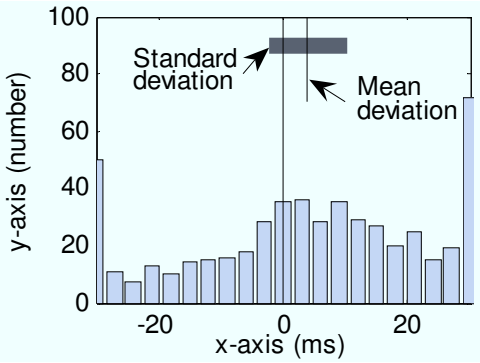

Figure 3. Mean, standard deviations and histogram of differences between the experts' QT markings and the findings of the suggested algorithm.

The fully automated method was developed with a feedback to a previously published median of expert markings of the same database [13].

Results are obtained for 522 recordings, or 95% of the whole database. Histogram of the differences between the experts' markings and the findings of the suggested algorithm are shown in Fig. 3. The mean and standard deviations are 3.86±12.52 ms.

The score for the Challenge 2006 is 25.19 and is the second best in the fully automated Division 3 [1].

5. Discussion and conclusions

Analysis of the differences between the experts' markings and the findings of the suggested algorithm proved that they are mostly due to the fact that results are obtained from different heart beats. The same is valid for the Challenge, where Divisions 2 and 3 require automatic random selection of a representative beat. In our opinion the accuracy is acceptable for clinical evaluations and will rise if interbeat QT interval variations can be excluded from the results.

Acknowledgements

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