New Algorithm for QT Dispersion Analysis in XYZ-Lead Holter ECG. Performance and Applications

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Abstract

In this paper a new algorithm for automatic analysis of QT dispersion (QTd) in three-lead (X, Y, Z) Holter ECG records is presented. To evaluate its performance we have compared automatic with manual annotations, using a set of 1000 beats of Holter ECG records from the IDEAL Data Base. The signals have been automatically analyzed and the same beats have been analyzed by two cardiologists. The results obtained show that the reproducibility of the automatic QTd measurement is comparable to manual. QTd has been studied as a discriminator of patients with Dilative Cardiomyopathy from healthy subjects. We have found that QTd in 24 hours presents statistically significant differences when comparing subjects from those two groups. We have analyzed also mean and standard deviation of RR, QT and QTc intervals to determine their statistical significance in discriminating subjects from both groups.

1. Introduction

When non-homogeneities are present in the ventricle repolarization phase, QT intervals measured in the same beat from several leads can differ notably from one to another. This is what QT dispersion (QTd) measures: the difference between the maximum and minimum QT intervals measured in one beat from different leads

$$QTd = QT_{max} - QT_{min} \qquad (1)$$

Several works dealing with manual measurement of QTd have been published [1, 2, 3], analyzing twelve standard leads. Some studies show that there is a good correlation between manual measures of QTd using 12-lead ECG and 3 orthogonal lead ECG [4].

In this paper a new algorithm for automatic analysis of QT dispersion (QTd) in three-lead (X, Y, Z) Holter ECG recordings is presented. The proposed algorithm is based on the wave boundary detector, proposed and validated by our group [5, 6], that uses the first derivative of the ECG signal, and recognizes T-wave morphologies.

It is generally difficult to obtain consistent measures of the QT interval in leads where there is a low signal to noise ratio. In this way, we have implemented an algorithm to solve the difficulties that might be present at the beginning of the QRS complex or at the end of the T wave.

In this paper we have worked with digital Holter ECG signals from the IDEAL Data Base [7], 3 orthogonal lead signals sampled at a frequency of 200 Hz. Those signals belong to healthy subjects and to patients with several cardiac pathologies.

To validate the algorithm two experts analyzed separately the signals from IDEAL Data Base, since annotations for those signals were not available as a reference.

The presented methodology has been applied to the analysis of 24-hour Holter ECG signals that come from patients with Dilative Cardiomyopathy, and from healthy subjects.

2. The QT dispersion algorithm

The proposed algorithm has been organized in three steps (Figure 1):

(a) A single-lead detector of significant points [5, 6] is applied to each one of the three leads.
(b) Interval measuring, using the significant point detection performed above.
(c) QT dispersion, calculated applying equation (1),

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using the results obtained in (b).

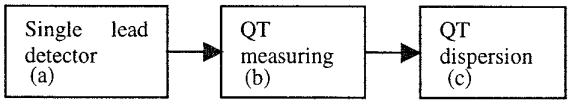


Figure 1. The proposed algorithm

When using the single-lead detector, in some leads there were the following problems in QT detection:

1. When significant noise was present, and due to some very specific QRS morphologies, the beginning of QRS was not very well detected, as it is shown in Figure 2. This error was committed mostly when no Q wave was present.
2. T-end definition is a function of the T-wave morphology, but at the same time, introduces error when misidentification of the morphology occurs.

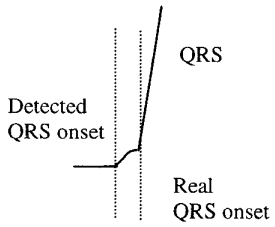


Figure 2. Misdetection of the beginning of the QRS due to noise level in the ECG.

Those two problems have been solved in step (b) of our algorithm (Figure 1), when measuring intervals. It includes the fixed QR method, that is applied whenever needed, and the post-processing of the resulting QT intervals.

2.1. Fixed QR method

This method is based on the assumption that the RT segment measurement is more robust than the QT interval measurement. The method considers a constant QR value throughout the signal and only for the lead where a Q detection problem is present. This QR constant value is added to each RT segment, and the result is a correct QT interval.

The QR value for a particular lead is determined from the analysis of the first 50 QR-segments of that lead. Their mean value and standard deviation are measured, and a characteristic QR is selected.

This method should be applied when the following criteria is completely fulfilled:

1. The standard deviation of the QR segments is larger than a threshold.
2. The histogram of the QR segments presents two or more peaks clearly distinguishable.
3. QR variability is due to the beginning of Q and not to the peak of R.

2.2. Post-processing of QT intervals

The post-processing stage in the algorithm is proposed in order to minimize the error committed when detecting the end of T wave.

Our main objective here is to obtain well-measured values of QT for each lead, thus the post-processing stage will always be applied.

Whenever a QT interval is measured in a lead, the following steps should be followed:

- Compute the mean value of the last QT intervals correctly measured ($\overline{QT}$).
- The next QT interval will be considered well measured provided that it fits in the interval [0.9* $\overline{QT}$, 1.1*$\overline{QT}$].

It is extremely important to check that the first five beats considered for the analysis have the end of T well detected, because they are used to define the initial parameters of this post-processing stage.

By considering only the last QT intervals preceding the just measured interval we are allowing the algorithm to adapt to the variations of the QT interval throughout the 24 hours.

3. Algorithm validation

A set of 1000 beats (50 beats of 20 subjects) of digital Holter ECG recordings from healthy subjects of the IDEAL Data Base were used for the validation of the algorithm. These beats present different T-wave morphologies and different noise levels. The fixed QR method was applied whenever needed.

The automatic results (AUT) have been compared with those obtained individually by the two experts, C1 and C2, for the same set of beats.

Table 1. Validation results of the algorithm. 20 records from healthy subjects of the IDEAL Data Base were used (1000 beats). Values are expressed as m ± sd (ms).

AUT – C1	AUT – C2	C1 – C2
0.62 ± 12.00	-0.34 ± 11.90	0.26 ± 13.09

The parameters studied to validate the algorithm are the mean difference and its standard deviation (m ± sd) between automatic and manual QTd measures, AUT – C1 and AUT – C2, and between the experts QTd measures, C1 – C2.

From the values of Table 1 can be deduced that the automatic values are perfectly acceptable because both their mean and their standard deviation are of the same order as the mean difference and its standard deviation obtained between the experts. On the other hand, the records sampling period is 5ms, so smaller differences or variations than 5ms cannot be required.

Table 2 shows the importance of applying the fixed QR

method to the QT measuring. In it we can see the validation results obtained for some of the signals that needed that methodology to correct the beginning of QT interval. The results of m ± sd were obtained without the fixed QR method, and m* ± sd* applying it.

Table 2. Comparison of the results obtained for some of the records where fixed QR method should be applied. m* ± sd* (ms) and m ± sd (ms) are the mean and standard deviation obtained with and without the fixed QR method, respectively.

AUT-C1		AUT-C2		C1-C2
m ± sd	m* ± sd*	m ± sd	m* ± sd*	m ± sd
6.6±12.7	6.5±11.3	3.4±11.8	2.6±11.6	3.9±12.0
-18.3±12.1	-9.2±7.4	-15.0±14.1	-5.8±7.4	-2.9±7.6
2.5±14.1	4.0±9.7	9.2±18.0	6.0±15.6	-2.4±12.2
-16.7±19.3	-9.4±16.1	-14.6±20.3	-6.7±16.6	-0.4±17.5

4. Application to healthy and dilative cardiomyopathy subjects

The presented methodology has been applied to analyzing 24-hour Holter ECG signals from patients with Dilative Cardiomyopathy, and from healthy subjects.

We have worked with records from the IDEAL Data Base: 20 from healthy subjects and 20 from patients with Dilative Cardiomyopathy.

In order to compare both groups we have worked with the following parameters:

1. Mean values and standard deviations of QTd, RR, QT, and QTc (QT corrected by Bazzet's formula), in 24-hour Holter recordings.
2. Percentage of beats in 24-hour ECG with a QTc higher than a threshold. The threshold value used is 500u, according to [8].
3. Percentage of beats in 24-hour ECG with a QTd higher than a threshold. In this case we considered different thresholds.

RR, QT and QTc interval analysis were measured from the lead that had best signal to noise ratio.

4.1. Mean values and standard deviations of QTd, RR, QT, and QTc

Table 3 shows the mean values of the studied parameters in 24-hour ECG recordings from both groups, healthy subjects (H) and patients with Dilative Cardiomyopathy (DC). Last row also shows the statistical significance level of each parameter to discern subjects from each group. Table 4 shows the standard deviations of the studied parameters in 24-hour Holter recordings from both groups.

Table 3. m ± σ (ms) of the analyzed intervals. Healthy (H) and Dilative Cardiomyopathy (DC) subjects. Statistical significance level p.

	RR	QT	QTc	QTc>500u	QTd
H	811±109	376 ± 25	423 ± 20	4 ± 4	32 ± 11
DC	722±116	416 ± 46	478 ± 50	30 ± 36	52 ± 32
p	n.s.	0.002	0.000	0.002	0.011

From those results we can conclude that the mean values of QTd, QT, QTc and the percentage of beats with a QTc value higher than 500u, present significant statistical differences when comparing both groups. On the other hand, while the average of the RR intervals is not statistically significant to discriminate from both groups, its standard deviation is the only able to discriminate between subjects from all the standard deviations studied (Table 4).

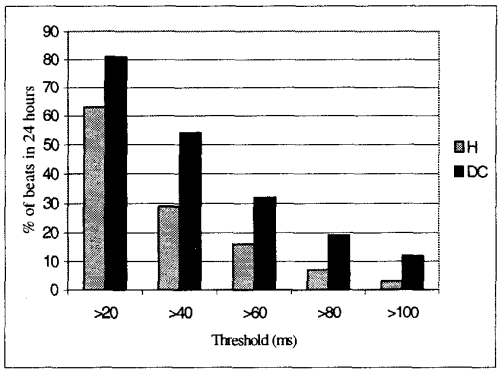
Table 4. sd ± σ (ms) of the analyzed intervals. Statistical significance level p.

	RR	QT	QTc	QTd
H	159 ±.44	33 ± 9	30 ± 8	24 ± 6
DC	113 ± 64	31 ± 11	28 ± 11	28 ± 17
p	0.012	n.s.	n.s.	n.s.

These results have been obtained analyzing an average of 75,000 beats for each record.

4.2. Optimum QTd threshold

(a)



(b)

	>20	>40	>60	>80	>100
H	63 ± 22	29 ± 19	16 ± 12	7 ± 5	3 ± 2
DC	81 ± 24	54 ± 30	32 ± 27	19 ± 24	12 ± 20
p	0.019	0.003	0.022	0.043	n.s.

Figure 3. Percentage of beats with a QTd higher than different thresholds. H = healthy subjects. DC = patients with Dilative Cardiomyopathy. Statistical significance level p.

The percentage of beats in 24-hour ECG with QTd higher than different thresholds has been calculated and its

statistical significance level has been evaluated in order to choose the best threshold. From the results shown in Figure 3 we can conclude that the most significant threshold is 40 ms, the one with the lowest p ($p<0.003$).

This percentage of beats with QTd > 40ms improves the statistical significant level of the mean QTd value, and obtains the same significance as mean QT and the percentage of beats with QTc > 500u.

5. Discussion and conclusions

Healthy patients will usually have a uniform repolarization process, thus we will likely obtain small QTd values with an also small variability. Figure 4 shows the dynamic behavior of QTd from a healthy subject for 24 hours.

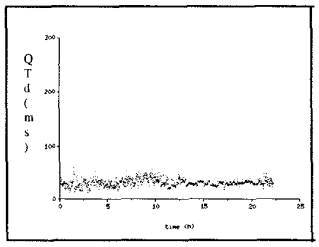


Figure 4. 24-hour QTd values for a healthy subject.

When there are non-homogeneities in the ventricles repolarization process, QT values will be different in each lead for the same beat. Thus we will expect higher mean values and variability. Figure 5 shows the dynamic behavior of QTd from a patient with Dilative Cardiomyopathy in a 24-hour record.

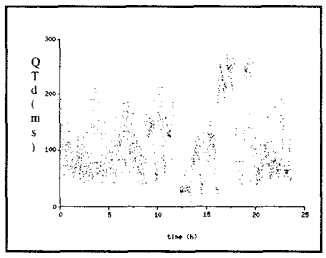


Figure 5. 24-hour QTd values for a patient with Dilative Cardiomiopathy.

The results that we present in this paper completely agree with those hypotheses. Mean QTd in 20 healthy subjects (32 ± 11) is significantly smaller than QTd measured in 20 patients with DC (52 ± 32).

According to this we have also established a QTd threshold. For this population, the percentage of beats in 24-hour ECG with QTd higher than the threshold of 40 ms presents significant statistical differences when comparing Dilative Cardiomyopathy patients with healthy subjects.

On the other hand, mean QT and QTc values, as well as the percentage of beats with a QTc higher than 500u, are significantly smaller in Holter ECG from healthy subjects than in Holter ECG from DC patients.

Even though the statistical significance of QTd is not higher than that from QT or QTc, it can give some complementary information. Using all indexes together can improve the overall stratification power.

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