QT interval detection and verification methods

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Abstract The aim of this study is to compare methods for T-wave end detection and QT interval computation and to discuss the importance of interactive result verification. The comparison includes methods for minima detection, a regression method and a method based on signal derivation. All these methods were tested on ECG data with high QT interval variability and high signal distortion.

I. Introduction

QT interval is the interval between the beginning of the QRS complex and the end of the T wave; it reflects the repolarization function of the heart. QT interval prolongation is an important marker of increased risk for malignant ventricular tachycardia and fibrillation. Duration of the QT interval is significantly dependent on actual heart rate (RR interval) and this relationship has been characterised by different correction formulas with some debatable results. QT interval physiological duration varies between 0.3-0.4 s and should not be longer than 0.425-0.445 s.

II. Methods

Data: 3-lead ECG (SpaceLabs) was recorded in 24 healthy subjects for 23 minutes during an exercise (cycling) test in the supine position. Measurements were performed in the Clinical Research Center Brno, St. Anne's University Hospital. Protocol was as follows: – 3 min. rest, 5 min. cycling, 5 min. rest, 5 min. cycling, 5 min. rest. Digitalization was by 16-bit ADC with 500 Hz sampling frequency and recording and processing by ANNAlab-ScopeWin QT software [1]. During cycling with a mean load of 1 Watt/kg heart rate significantly increased (usually two-fold). T waves were distorted by body movement and ventricular repolarization vector declination changes. These measurement conditions provided various combinations of signal distortions.

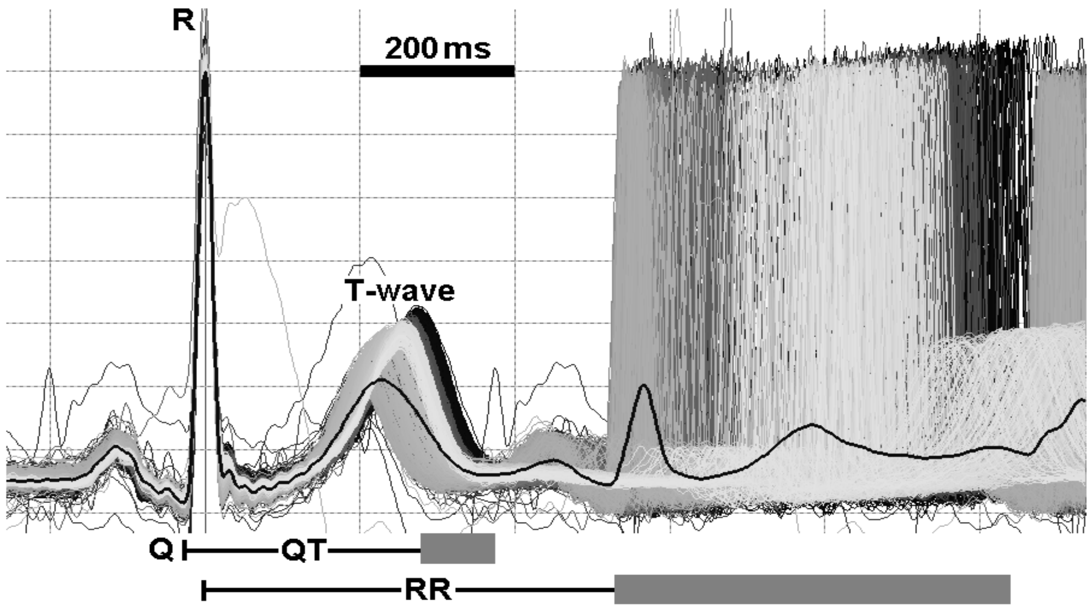

Figure 1. Segmented ECG, trigger R wave, 23 min. measurement, approximately 2,000 heartbeats drawn on top of each other. The time axis is demonstrated by different levels of greyness – from black (initial beats) to light grey (latest beats).

Off-line pre-processing: band pass 0.5-45 Hz filter, segmentation with R wave peak trigger. Fig. 1 demonstrates the drawing of all segments (beats) from the whole 23 min. measurement. The different shades of grey represent the time axis.

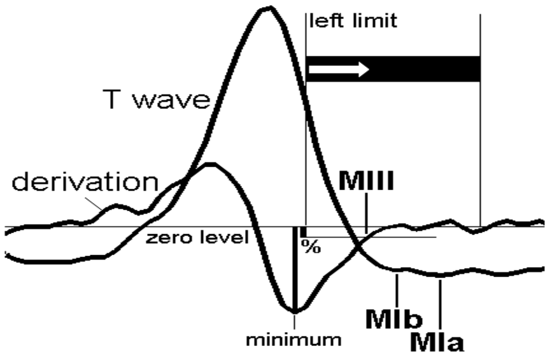

Figure 2. Representation of graphic methods MIx and MIII: MIa - detection of global minimum in selected region – between vertical cursors, MIb - detection of first local minimum from left limit, MIII - detection of T wave end from derivation of ECG.

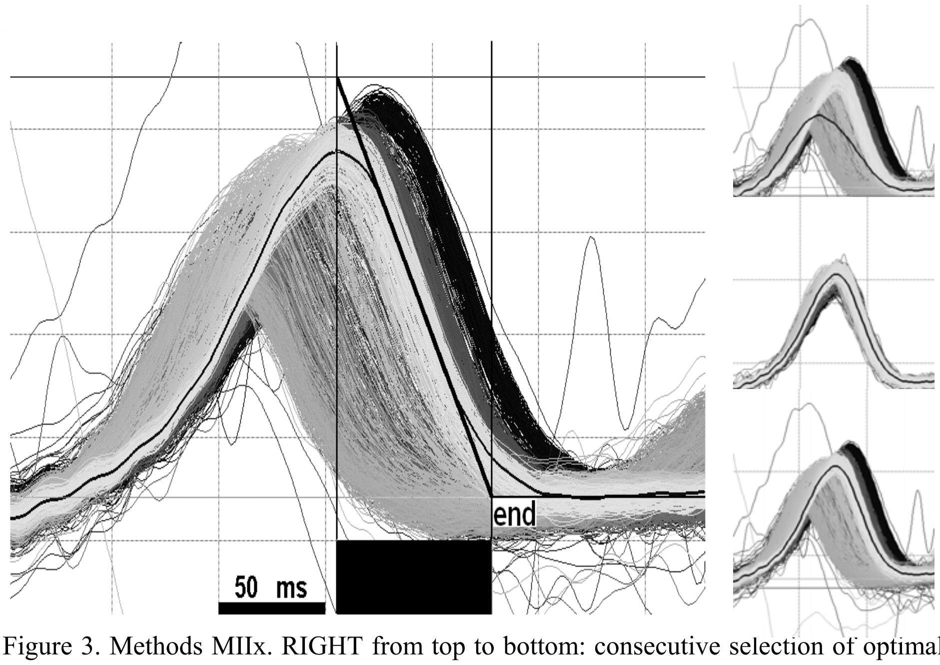

Figure 3. Methods MIIx. RIGHT from top to bottom: consecutive selection of optimal T wave shape, the thick black line represents an average from selected T waves, LEFT: the thick black curve represents the regression model - average. The end of each T wave is computed as the least square optimized time shift of the regression model. The region of the regression model (most frequently the descending part of the T wave) is limited by vertical cursors - black rectangle. The right limit of this region is defined as the point of the intersection of the descending T wave tangent and mean level of foot - isoelectric line (end). The left limit is predominantly given by the maximum of the regression model. The setting of limits is performed by the operator and represents an important phase of QT detection.

Our aim was to develop a high-performance tool for credible T wave end detection. We tested three different methods as defined below. There is a description of these methods (MI-MIII), a description of their properties and a definition of starting parameters :

Methods **MI**: minima detection in descending T wave part.
Method **MIa**: determination of the global minimum in the selected range (Fig. 2. MIa).
Method **MIb**: determination of the first local minimum from the left limit (Fig. 2. MIb).

Methods **MIIx**: regression analysis of T wave shape. The end of each T wave is defined as the least square optimized time shift between T wave and regression model (Fig. 3.).
Method **MIIa**: The regression model (average) is computed from all non-artefact segments.
Method **MIIb**: The regression model is computed as an average from segments selected interactively by the operator, see Fig. 3. RIGHT. Following this the least square method is used for computation of mutual T waves – regression model time shifts.

Method **MIII**: the T wave end is defined as the position of a percentage level (typically 10-20 %) of the minimum of first ECG derivation (Fig. 2. MIII).

An important part of T wave end detection is the definition of filters and starting parameters. This differs depending on methods and data character. This point is operator dependent. Graphical interpretation of data and the possibility of inspecting RR and QT variability and T wave end distortion at all analyzed time intervals play a crucial role. During the exercise test the shape of the T wave may change and the T wave end may be undetectable. Starting parameters defined interactively by the operator for the chosen method include: MI: the region for local or global minima detection; MII: the characteristic regression model, end of T wave in regression model (Fig. 3), if necessary - separation into independently investigated intervals; MIII: the percentage level from minimum of derived signal and left time limit for detection start.

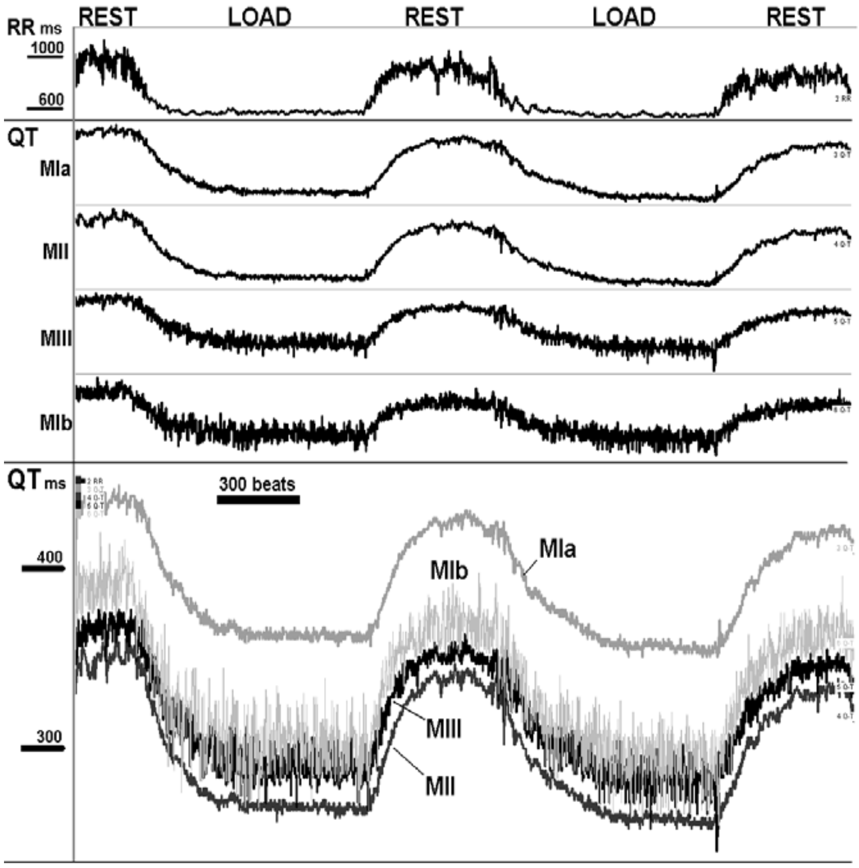

Figure 4. QT detection results, data from Fig. 1., TOP – RR and QT detected by four methods - MIa, MIIb, MIII and MIb. BOTTOM: QT graphs with the same vertical axis (ms). MIa prolongs the QT interval by about 80 ms, MIb and MIII are very noisy.

III. Results

There seems to be no universal method offering error-free results. The QT intervals detected by all the given methods are compared in Fig 4. Method MI is simple but extremely sensitive to signal noise and T-wave end shape distortion. The recommended band pass in this case is 1-20 Hz (MIa) or 1-40 Hz (MIb). Method MIa is disposed to prolong the QT interval, while method MIb is extremely sensitive to high frequency noise. The regression methods MIIa and MIIb are less sensitive to T wave end distortion and are almost resistant to noise. They can, however, provide incorrect results when the regression model radically changes during the investigated time interval. Last but not least, the condition of model shape stability is a general problem and the results depend entirely on the operator and its skills. A great advantage of the presented methodology is the interactive T wave characteristic shape and end inspection and selection by the operator. Separate time intervals should be used in the case of a significant T wave shape alteration. Method MIII uses a derivative signal requiring the ECG to be smooth. The recommended band pass is 0.5-20 Hz. This method is extremely sensitive to T wave end distortion.

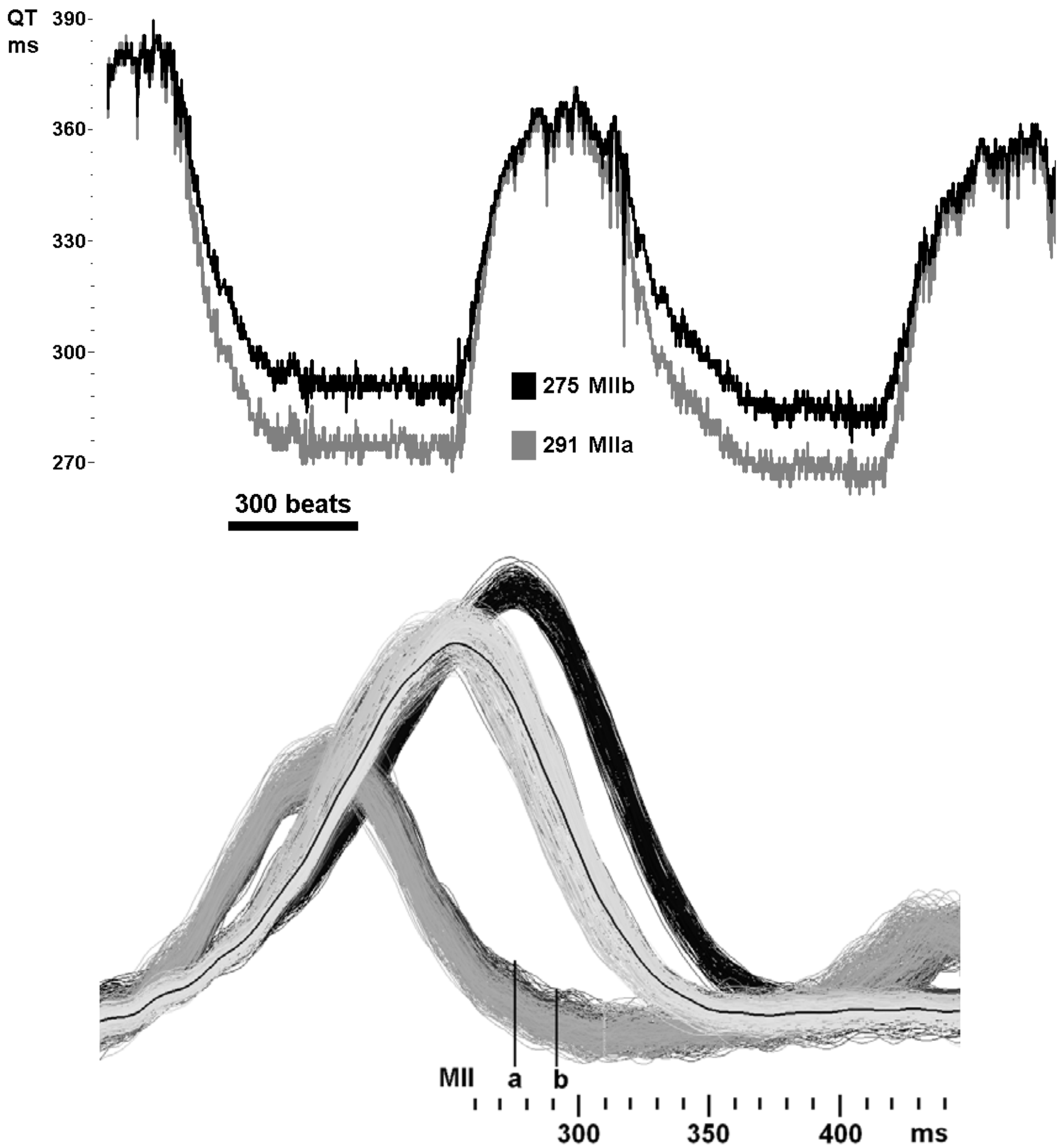

Figure 5. Comparison of regression methods MIIx and demonstration of the detected T wave end error. TOP: the shape of T wave ends detected by two methods. Both curves were normalized to 380 ms at rest at the start of the experiment. MIIa uses one regression model computed as an average from all T waves (Fig. 1, thick line), MIIb use regression model computed as an average of selected segments (this Fig. below, thick black curve). BOTTOM: different T wave shapes (black – rest before cycling, dark grey – cycling, light grey – rest after cycling), MII a,b – detected position of detected T wave end by MIIx methods during cycling.

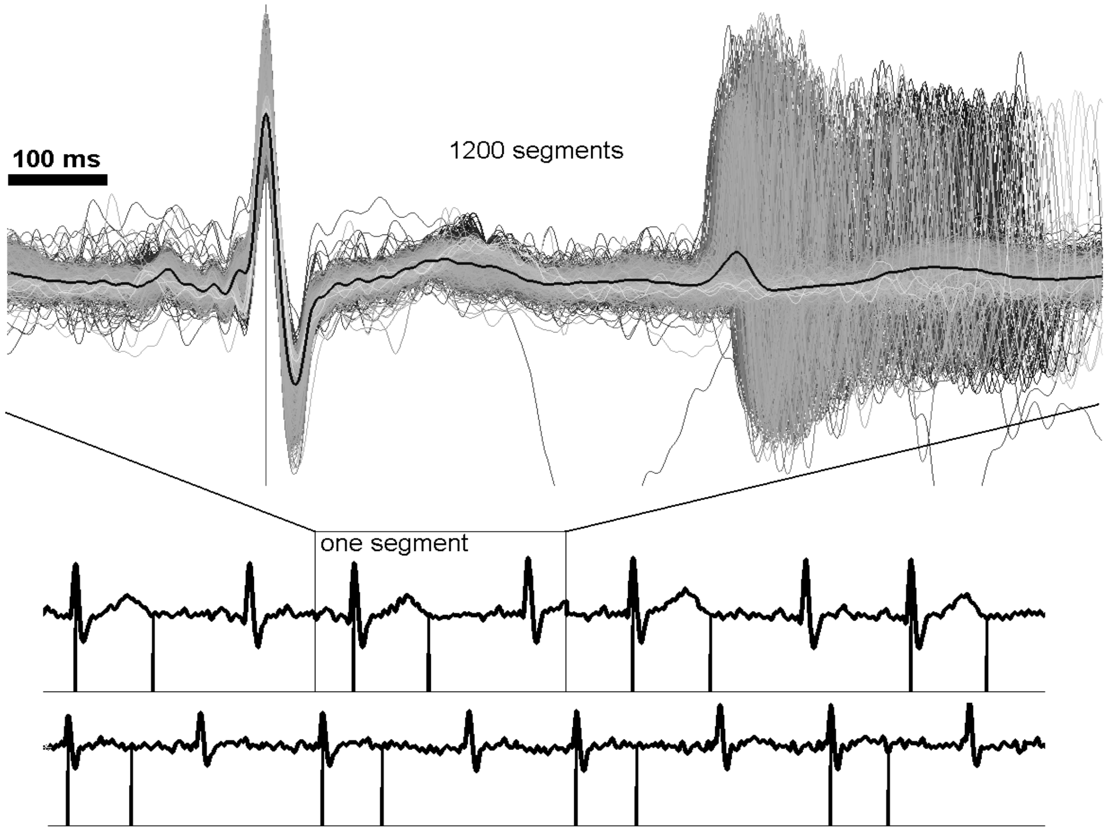

Figure 6. Example of method MII applied to a strongly distorted ECG signal. The upper part of the figure shows a chart of all 1,200 heartbeats processed. In the lower part is an example of two sections (rest and load). Vertical marks point to the R wave and to the end of the T wave. The T wave during load is extremely weak and the results obtained may be debated.

IV. Conclusions

The aim was to develop and define interactive tools for precise estimation of QT intervals over long-term measurements. Our data show that the optimal solution is the combination of graphical data interpretation - verification with a robust detection algorithm. This is the method MIIb and interactive determination of initial parameters, with graphical verification and editing of the QT intervals detected. Some authors compensate for the lack of an interactive verification procedure by using more than one different automatic method [2] and consecutive computation of the median QT interval. This solution is easier for the operator, but may contain significant hidden errors.

The MII methods use a regression model obtained as an average from multiple T waves. Other solutions, which use analytical models, also exist. As an example we could mention the discrete wavelet transform (DWT) and Markov models. These techniques would be tuned to unique spectral and time ECG waveform features. Unfortunately, substantial T wave shape variability may cause incorrect results for these methods.

Acknowledgement This work has been supported by the grant project GACR no. 102/02/1339.

References

[1] Lanfranchi P, Shamsuzzaman A S, Ackerman M J, Kára T, Jurák Pavel, Wolk R, Somers VK: Sex-selective QT prolongation during rapid eye movement sleep, In: Circulation, Vol. 106/12, 2002, page 1488 – 1492.

[2] Batchvarov VN, Ghuran A, Smetana P, Hnatkova K, Harries M, Dilaveris P, Camm A J, Malik M, QT-RR relationship in healthy subjects exhibits substantial intersubject variability and high intrasubject stability, In Am J Physiol Heart Circ Physiol Vol. 282, Issue 6, H2356-H2363, June 2002.