Improving Reliability of 'Total-Cosine-R-to T' (TCRT) in Patients with Acute Myocardial Infarction

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Abstract

The parameter TCRT (Total Cosine R-to-T) calculated from ECG recording has been shown to have a remarkable prognostic value as a predictor of the outcomes of the coronary artery disease and the acute myocardial infarction (AMI) patients. The TCRT is conventionally calculated using an algorithm produced by Acar et al. (1999). In this study, the reliability of the TCRT algorithm was tested with the ECG data of the healthy group (n=25) and the AMI group (n=45). Typical problems occurred in the detection of the maximum of the T vector (9% of patients), the bounding of the R wave (18%), a comprehensive segmentation (11%), and a decreased congruence between TCRT and the spatial QRS-T angle (33%). The results show that small improvements to the basic algorithm can decrease the number of failures up to 82% in AMI data. It is concluded that segmentation properties should be improved in the basic TCRT algorithm in order to maintain the diagnostic value of TCRT in different patient data.

1. Introduction

The relationship between the QRS complex and the T wave, expressed as an angle between the spatial QRS wave and the spatial T wave (QRS-T angle), has been a subject of interest for more than 70 years in ECG (electrocardiographic) research [1,2,3]. One of the most often used parameter for measuring the spatial QRS-T angle has been developed by Acar et al. in 1999 [4]. The parameter is the averaged cosine of the QRS-T angle, 'total cosine R-to-T' (TCRT). An increase of the QRS-T angle, and therefore a decrease of TCRT, implies a dissociation of the normal relationship between the depolarisation and the repolarisation.

TCRT has been shown to have remarkable prognostic value as a predictor of the outcomes of the coronary artery disease and the postmyocardial infarction patients [5,6,7]. Especially depressed TCRT has been strongly associated with increased cardiac mortality after AMI (Acute Myocardial Infarction) [6].

Although TCRT is widely used, the algorithm has not been tested with diverse ECG materials. For instance, during acute myocardial infarction, ECG evidently differs from healthy ECG. The changes in ECG waves depend, among others, on the size, location, and development step of the myocardial infarction. Typical changes of the myocardial infarction are inverted and symmetrical T waves, ST elevations, wide QRS complex, Q waves and reduction of the R wave [8].

In order to use TCRT parameter as a diagnostic value, it should also function with abnormal ECG. In this study, we investigate how the TCRT maintains its reliability as a diagnostic value in patients with ECG distortions due to acute myocardial infarction. The computing problems of the TCRT are divided into four groups and proposals for improvement are presented and tested.

2. Computation of TCRT

Acar's algorithm converts 12 lead standard ECG to a minimum dimensional space within the optimized SVD (Singular Value Decomposition). QRS and T-wave detection is performed on the three decomposed signals (s_{3D}) that contain the most of the energy. The magnitude vector E_{3D} is defined as $E_{3D}(t_i)=||s_{3D}(t_i)||_2$.

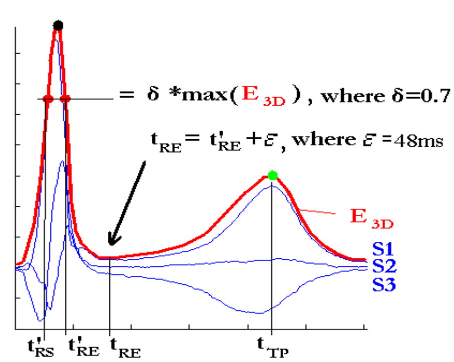

Figure 1. QRS and T wave detection according to [4].

Fig. 1 shows the decomposed signals, s_{3D} (blue lines), and the magnitude vector E_{3D} (red line) for a single beat. The s_{3D} can be visualized as loops in orthogonal three-dimensional space (see Fig. 2). Furthermore, TCRT parameter is the averaged measure of the cosines of the angles between the vectors of QRS (defined from t'_{RS} to t'_{RE}, Fig. 2) and the maximum of the unit vector $e_{T,1}$. The vector $e_{T,1}$ reflects the orientation of the T wave loop. The locations of the t'_{RS} and the t'_{RE} are defined by the threshold value δ (see Fig. 1). Normally δ=0.7 and the t'_{RS} and the t'RE are placed on the both side of the R peak, where the E3D falls 70% of its maximum value. According to Acar, the peak of the T wave (tTP) is the maximum point of the E3D after the tRE. The tRE is the R-peak+value (normally =48ms).

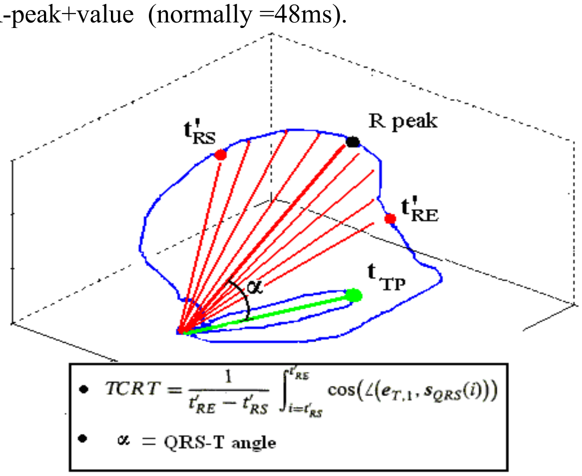

Figure 2. The data of the Figure 1 is illustrated as loops. TCRT is calculated as a mean value between red lines and green line and the angle α is the angle between the main vectors of the QRS and T loops.

3. Study population and signal processing

The study group comprised 45 STEMI (myocardial infarction with ST segment elevation) patients (age 69± 11). The ECG's were recorded from patients with acute myocardial infarction. The recordings were taken in health centres, rescue helicopters and the intensive care unit of the University Hospital of Oulu. The ECG's were stored as paper prints, which were scanned, digitized, and analyzed with the method presented in [9].

Healthy people (n=24, age 44± 10) were used as a control group. The ECG was digitally recorded with a Welch Allyn Cardiocontrol BV Digital ECG recorder (Welch Allyn Inc., Skeneateles Falls, USA), in the University Hospital of Oulu. All data were taken without the build-in filter in the ECG recorder. The sampling frequency was 600Hz.

In the analysis, the window of the 12 lead ECG beat was defined to start in the middle of the iso-electric section before the QRS complex and to end in the next corresponding location. A linear baseline fit was estimated from the start and end points and subtracted from the signal. The s_{3D} was calculated using SVD [4]. The TCRT parameter was computed using the algorithm described above. The cosine of the spatial QRS-T angle (cos(α)) was used as a reference value for the TCRT. For calculating of the cos(α), the locations of the T peak and the R peak were manually selected (see Fig. 2.).

4. Improvements for the computation problems of TCRT in AMI patients

Problems with the computing the TCRT value were supposed to be caused by atypical ECG changes. Since many kind of changes in ECG are occurred during acute myocardial infarction, the problems were divided into four groups. In addition, proposals for improvement were described for each problem separately and the occurrences of the each problem, both in a healthy group and in the patients with acute myocardial infarction, were calculated as well.

4.1. Incorrect detection of maximum of T vector

A ST elevation is a typical change in the ECG during the acute myocardial infarction [10]. In a severe hypoxia, T wave apex (marked as t_{TP}) may not exist at all, but the wave goes downward from a point t_{RE} to the end of the T wave (t_{TE}). This causes the incorrect detection of the value t_{TP} , and therefore maximum of the unit vector $e_{T,1}$. Furthermore, in patients with a wide QRS complex, the value t_{TP} can be computed incorrectly as a part of the QRS complex (see Fig. 3a), which causes the total error in the computing of the TCRT.

In the present study the Acar's algorithm was completed as follows: If the apex of T wave, t_{TP}, was detected too early (<20ms after the t_{RE}), it was defined as a maximum value in a range [x± 60ms] , where x is a mean value between the values t_{RE} and t_{TE} (see Fig 3a). Furthermore, if the original algorithm did not recognise the t_{TP} at all, the t_{TP} was defined to be the value x.

Results: The occurrence of the incorrect detection of the maximum of the T vector was zero in the healthy group and 9% (n=4) with the patients. Using the corrective proposals, the problem completely disappeared in the patient data, see Table 1.

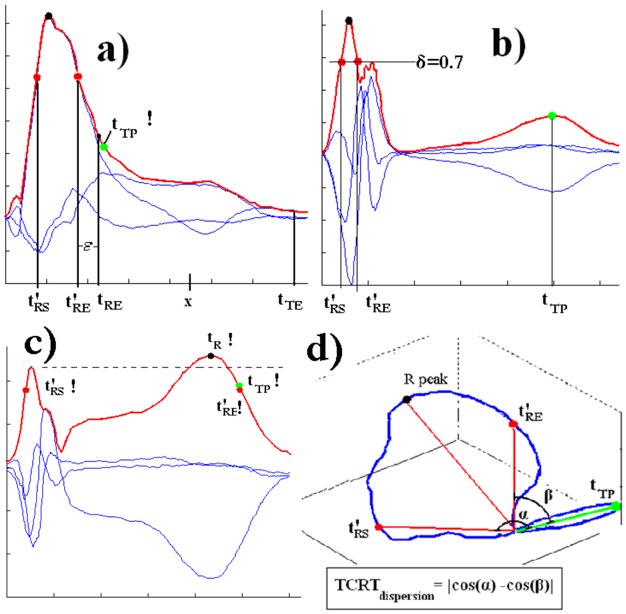

Figure 3. a) The incorrect detection of the maximum of the T vector. b) The R wave was bounded either partially or completely by the original algorithm. c) Comprehensive segmentation problem. All the segmentation points are localized incorrect. d) $TCRT_{dispersion}$ describes how large view of the QRS loop is used for the defining of the TCRT value.

4.2. Incorrect bounding of R wave

The R wave of the E_{3D} signal distributes to multiple parts in the case of some patients (see Fig. 3b). The phenomenon is probably based on the fragmentation of the R wave, which can occur in some individual channels of the ECG in myocardial infarction patients [11,12]. Due to the fragmentation of the E_{3D}, the R wave is bounded either partially or completely by the original algorithm. Consequently, the fragmentation produces distorts in the results of the AMI data. The threshold value δ was set to 0.7 in Acar's algorithm, but in this study the value δ was tested to decrease to 0.5 in order to bound the R wave completely in all of the cases.

Results: Using the value δ=0.7 the R wave was bounded erroneously in 18% of the patients. Decreasing the δ value to 0.5, the occurrence of the error fell to 7%. The occurrence in the healthy control group was zero, see Table 1.

4.3. Comprehensive segmentation problem

In the case of a comprehensive segmentation problem, all segmentation points are localized incorrect. The problem is caused by the large negative T-wave, which is a typical phenomenon of the myocardial infarction.

The large negative T wave in an individual ECG lead (s_1-s_3) means a large positive T wave in the E_{3D} signal (see Fig. 3c). If the T wave is higher than the R wave, the T wave is supposed to be the R wave by algorithm. In this case, the error in the TCRT computing is total.

If a single beat is bounded from ECG data before the TCRT analysis, the R peak can be supposed to locate in the first third of the selected ECG beat.

Results: The problem was occurred in the 11% of the patients (n=5). Using the preceding proposal for improvement, only one case was disturbed. Also this problem did not appear in the healthy group.

Table 1. The occurrences of the computing problems of the TCRT in AMI patients and in healthy people

Problem	Patients, n=45 original TCRT algorithm	Patients, =45 orig. algorithm after corrections	Healthy people n=25, orig. algorithm
1.	9% (n=4)	0%	0%
2.	18% (n=8)	7%(n=3)	0%
3.	11% (n=5)	2%(n=1)	0%
All (1-3)	**n= 17**	**n= 4**	**n=2**

4.4. Decreased congruence between TCRT and spatial QRS-T angle

The fourth problem is not so obvious than the first three. Instead, this can be referred to as a minor risk for the reliability of the TCRT.

A wide QRS complex is a typical ECG reflection in the patients with myocardial infarction [13]. The wider the QRS complex, the more sub-TCRTs exist, from which the actual TCRT is calculated as a mean value (see Fig. 6).

The dispersion of the sub-TCRTs ($TCRT_{dispersion}$, see Fig. 3d) is a novel variable, which describes how large a view of the QRS loop is used for the defining of the TCRT value. The role of the $TCRT_{dispersion}$ is to clarify if the total TCRT is equal with the cosine of the QRS-T angle at all (cos(α) in Fig. 2). The $TCRT_{dispersion}$ can be 2 at the maximum, when the range of the TCRT values is [-1,1]. In the Figure 4a., the $TCRT_{dispersion}$ value is 1.1 and the TCRT parameter is calculated as the mean of the cosines between -0.9 and 0.2. This is over half of the range of the TCRT, which may decrease the exactness of the TCRT as a measure between the most dominant directions of the QRS and T loops. To order to assess that, an another novel variable, $TCRT_{difference}$, was defined as an absolute value of the difference between TCRT and cos(α). In this study, the $TCRT_{dispersion}$ was compared to the $TCRT_{difference}$ in order to evaluate how the TCRT, with increased $TCRT_{dispersion}$, maintains its similarity to the angle between QRS and T loops (cos(α)).

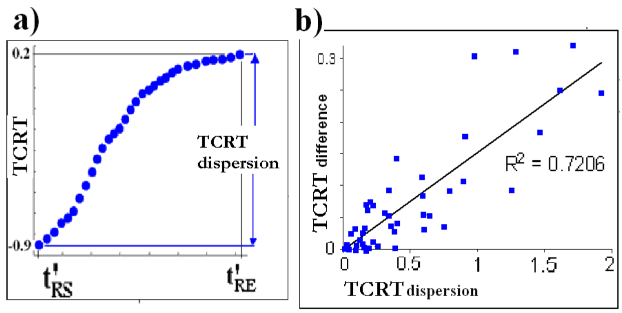

Figure 4. a) Extensive dispersion of sub-TCRT values between t'_{RS} and t'_{RE}. b) $TCRT_{difference}$ as the function of the $TCRT_{dispersion}$.

Figure 4b shows that the $TCRT_{dispersion}$ correlated strongly with the $TCRT_{difference}$ (R^2=0.72). It means that the TCRT, based on extended $TCRT_{dispersion}$, can not be paralleled with the cosine of the spatial QRS-T angle (cos(α)). The risk for the inexact definition of the cosine of the QRS-T angle was defined to exist if the $TCRT_{dispersion}$ was greater than 0.5. The limit value 0.5 is one fourth of the TCRT range. The $TCRT_{dispersion}$ was >0.5 in the 33% of the patients (n=15) and also in the 8% of the healthy people. Any particular proposal for improvement for minimizing the risk was not represented in the study. Nevertheless, the results inspired the question what actually are the benefits of the averaged Total Cosine R-to-T (TCRT) compared to the three dimensional QRS-T angle (cos(α)). According to Acar, the TCRT measures the deviation between QRS and T loops, and it, in effect, measures the difference of the propagation directions of the depolarization and repolarization waves [2]. But then again, also the simpler QRS-T angle measures the same deviation. On the grounds of the results of the study, the QRS-T angle might even be a more exact measure than the TCRT, at least in patients with severe ECG changes.

5. Conclusion

In this study, the reliability of the TCRT algorithm was tested with the ECG data of the healthy group (n=25) and the AMI group (n=45). Typical ECG changes such as inverted and symmetrical T waves, ST elevations, wide QRS complex, and reduction of the R wave occurred in the AMI group. Calculation of TCRT failed in several AMI cases due to severe segmentation problems with the ECG waves. Typical problems occurred in the detection of the maximum of the T vector (9% of patients), the bounding of the R wave (18%), a comprehensive segmentation (11%), and finally, a decreased congruence between TCRT and the spatial QRS-T angle (33%). The results show that small improvements to the basic algorithm can decrease the number of failures up to 82% in AMI data. The improvements obtained included: resetting of threshold values, better detection of the T peak, and finally, a more accurate model of the de-/repolarization sequence. It is concluded that segmentation properties should be improved in the basic TCRT algorithm in order to maintain the diagnostic value of TCRT in patients with acute myocardial infarction.

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