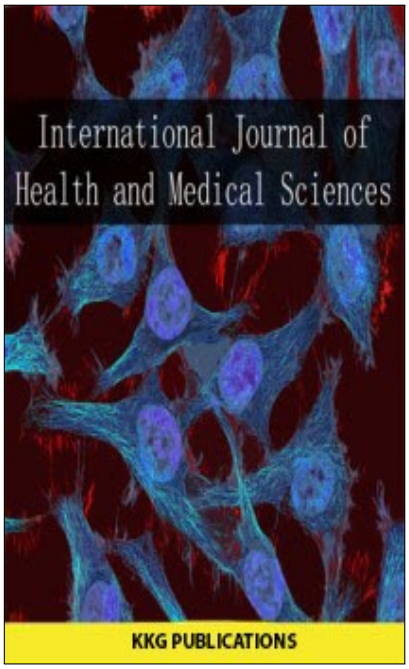

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A T-WAVE VARIATION CHARACTERISTICS EVALUATION ALGORITHM FOR ISCHEMIC HEART BEATS

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Abstract. During an exercise, muscle contraction occurs for body movements and requires more amount of oxygen. Then, the heart beating rate tends to increases during an exercise [1]. While the heart beating rate varies, the sympathetic nerve, respiratory, and blood circulation systems adapt to the muscle contracting. The sympathetic nerve system with a calcium ion handling problem causes abnormal myocardial actions and can develop arrhythmia [2]. However, the heartbeat electric signal variations through wearable electrodes are less noticeable without an electric signal data screening process. The proposed electric signal data screening process determines whether the ischemic heartbeat is present and evaluates the T wave variation characteristics from the standard deviation of amplitude and beat-by-beat duration comparison. The T-wave represents depolarization and repolarization of the left ventricle. The duration of the T-wave is from the Q point of the QRS complex and represents the QT interval. QT interval prolongation with the T-wave morphology becomes a biomarker of acute myocardial ischemia and represents the ventricular repolarization abnormalities [3]. This paper characterizes depolarization and repolarization actions of the left ventricle from the electric signal outputs of electrocardiography (ECG or EKG). The proposed electric signal data screening process evaluates beat-to-beat information of amplitude and duration of T-waves among electric signals from multi-electrode EKG. Among the experimental data in this paper, the heartbeat showing the maximum QT interval tended to have amplitude values with higher standard deviation. For the experimental 12-lead EKG data, certain beat-order tended to represent the maximum QT interval through the 12 channels. The experimental dataset from the channel with abnormal QT interval prolongation represented more dispersed QT intervals than the dataset from the other channel without abnormal QT interval prolongation.

INTRODUCTION

Wearable healthcare sensors equip electrodes to measure voltage difference between two electrodes. Muscle contraction generates slight voltage difference between the target location where muscle contraction occurs and the reference electrode location. When heart muscle actions show stable operation pattern, a voltage difference between a certain spot around the heart and a reference electrode shows stable repeating pattern. Arrhythmia represents the repeating pattern of heart muscle actions to be changed abruptly.

Various human body conditions including changes in the autonomous nerve, respiratory, and blood circulation system affect electric signal outputs from body-worn electrodes. Muscle contracting body movements generate extra muscle operating electric signals. The electric signals from the body movements interfere with the electric signal from heart actions, and change the electric signal output waveform of the body-worn electrodes. EKG shows a voltage differenced signal generated from heart actions.

As most exercises require more amount of oxygen for body movements, the autonomous nerve system and respiratory system manage to take more numbers of inhalation and exhalation. More numbers of inhalation and exhalation accompany more intense heart actions to deliver oxygen and carbon dioxide to increased blood stream. The submaximal efficiency of oxygen uptake accompanies increased exercise capacity [4].

The blood circulation condition of the human heart decides electric signal outputs caused from the heart actions representing current blood circulation conditions. The electric signals generated from the left ventricle actions, depolarization and repolarization, represent the electric signal waveforms of the QRS complex and T-wave. Infarct region during demand ischemia generates alternative collateral blood flow from myocardial wall thickening [5]. Acute myocardial ischemia due to low blood supply affects the depolarization and repolarization actions. The data points between the Q point of the QRS complex and the end point of the T-wave consist of QT interval.

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Figure 1 shows general heart beat electric signal waveform with the QRS complex, P- and T-wave, and interval between Q point and T-wave.

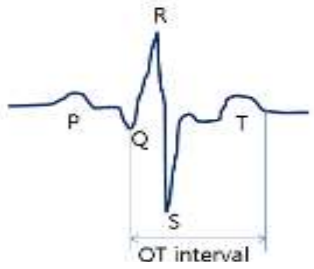

Fig. 1 *General heart beat electric signal waveform*

LITERATURE REVIEW

Acute myocardial ischemia represents increased amount of time to repolarize, and results in prolonged duration of T-wave and its morphology change [3]. Time duration of prolonged QT interval was 685 milliseconds [6]. As acute myocardial ischemia varies electric signal from the point S of QRS complex to the T-wave [7], QT interval that includes the S point of the QRS complex and T-wave has variation tendency for acute myocardial ischemia. QT interval prolongation represents the risk of acute myocardial ischemia [8], [9], [10].

QT dispersion is the differenced value between the heart beat with maximum value of QT and the heart beat with minimum value of QT [11]. The QT dispersion values in patients with vasospastic angina are higher than the QT dispersion values of their normal conditions, and the QT dispersion measurement may predict the risk of arrhythmia during ischemia [12]. Data numbers of QT interval represent time period because sampled data per second is fixed over entire sampled data.

METHODOLOGY

Sampled ECG data are evaluated for beat-to-beat detection of the S and R point of QRS complex. The beat-to-beat detection of the S and R point of QRS complex starts from morphological peak detection function supported by MATLAB. As the amplitude of QRS complex represents higher value than the amplitude of P- and T-wave, QRS complex is detected firstly from the peak detection function. As the left ventricle depolarizes, muscle contraction occurs to the left ventricle location and generates QRS complex.

T-wave occurs when the depolarized left ventricle starts to repolarize to recover initial volume and be ready to contain blood flow from the next cycle of depolarization. Considering T-wave representing similar amplitude with QRS complex, the proposed electric signal data screening process compares both peaks of the T-wave and QRS complex. As general heart beat electric signal waveform, which is shown in Fig. 1, the time period location of QRS complex is prior to the time period of T-wave. Then, the peak points of T-wave and QRS complex are relocated.

The proposed electric signal data screening process calculates interval values between R points of QRS complexes. From the predefined data location of the R points, ECG data between P wave and R points are identified. Between each P-wave and R point, the number of data locations during the amplitude decreasing becomes the number of data be shifted from the last data of each P-wave. The shifted data location from each P-wave then represents corresponding Q point of each QRS complex. From each peak point of T-wave, the differenced values among data represent decreased amplitude values. The imaginary ending point of T wave is when the amplitude decreasing trend from each peak point of T-wave begins to slow down.

QT dispersion represents the maximum QT interval difference among beats from a given sampled data-set. The QT interval is the duration difference between Q point of QRS complex and T-wave ending point. The QT dispersion is the difference between the maximum and minimum of beat-by-beat QT intervals. As QT dispersion values can be same among datasets, QT dispersion values are divided by the averaged QT interval values to represent relative QT interval dispersion. Relative QT dispersion value becomes higher when dataset with smaller averaged QT interval, and more difference between the maximum and minimum of QT interval. Relative QT interval is calculated as shown in equation (1).

$$\text{Relative QT dispersion} = \frac{[max(QTinterval)] - [min(QTinterval)]}{mean(QTinterval)} \tag{1}$$

The beat-order showing the maximum QT interval and the minimum QT interval for each dataset is evaluated in Table 1. In Table 1, the amplitude standard deviation values represent the amount of amplitude variation from each average dataset, and the duration of QT interval in time unit is evaluated for the case of QT prolongation.

As beats of each heart action sequence include P-wave, QRS complex, and T-wave, T- wave variation characteristics are evaluated for each heart action sequence. The Q point of QRS complex and the ending point of T wave derive the interval

between them, which is QT interval. The QT interval counts the number of data points between the Q point of QRS complex and the ending point of T. For a given sampled dataset, QT interval values are evaluated for each heart action sequence.

Acute myocardial ischemia causes blood flow abnormalities [13]. The blood flow abnormality varies depolarization and repolarization of the left ventricle as observed from ECG signal waveform. As prolonged duration of T-wave and its morphology change occurs during acute myocardial ischemia [3], QT interval is prolonged. Patients with vasospastic angina have higher values of QT dispersion as they have arrhythmia symptom during ischemia [12]. When ischemic blood flow represents left ventricle abnormalities, QT interval and QT dispersion have variation tendencies with becoming larger values.

TABLE 1
T-WAVE VARIATION CHARACTERISTICS

Dataset	Beat-order (Max QT interval)	Beat-order (Min QT interval)	Relative QT dispersion	Amplitude S.D (beat-order)	Duration of observed QT prolongation (sec)
TD51_1	12	14	0.1484	0.3411 (12)	
TD51_2	12	6	0.2049	0.3554 (12)	
TD51_3	12	6	0.4523	0.3345 (12)	
TD51_avR	12	7	0.1855	0.6063 (12)	
TD51_avL	3	12	0.4833	0.1942(3)	
TD51_avF	3	7	0.1824	0..2207 (3)	
TD51_v1	12	6	0.1916	0.7634(12)	
TD51_v2	13	9, 10, 17	0.1776	0.3692(13)	
TD51_v3	12	7	0.1736	0.5840 (12)	
TD51_v4	3	6	0.2791	0.4863 (3)	
TD51_v5	12	7	0.2692	0.2785 (12)	
TD51_v6	12	6	0.5166	0.1772 (12)	
TD52_1	9	14	0.1905	0.6607 (9)	
TD52_2	8,9	14	0.1461	0.6804 (9)	
TD52_3	13	1,2, 10, 14	0.2172	0.3489 (8*)	
TD52_avR	7	2	0.1276	0.3500 (7)	
TD52_avL	8	4,13,14	0.1615	0.5369 (9*)	
TD52_avF	8	3, 13	0.1256	0.4193 (8)	
TD52_v1	8	11,14	0.1983	0.8016 (7*)	
TD52_v2	15,16	2	0.1154	0.7542 (16)	
TD52_v3	7	13	0.1572	1.1943 (16)	
TD52_v4	7	13	0.2494	1.0182 (7)	
TD52_v5	7	13	0.2661	0.7093 (7)	
TD52_v6	8	13	0.2110	0.3336 (8)	
QTD51_1	6	7	0.3677	1.2165 (5*)	
QTD51_2	4	7	0.2511	0.9875 (5*)	
QTD52_1	8	4	0.2154	0.8484 (12*)	
QTD52_2	11	4	0.6379	0.7124 (11)	
STD300_1	2	1	0.4323	1.0424 (2)	
STD300_2	8	10	0.7508	3.5615 (4*)	
STD301_1	1	8	0.3408	1.0170(1)	
STD301_2	6	5	0.5613	0.6890(6)	
QTPM	4	6	0.0712	0.6475(5*)	0.904

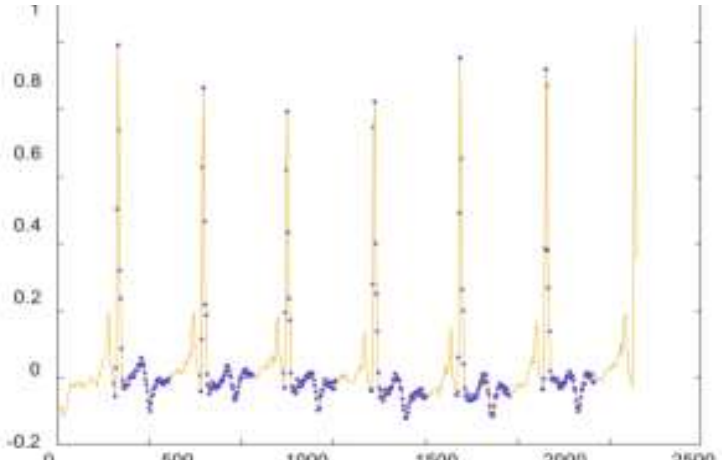

Fig. 2. *General heart beat electric signal waveform*

RESULTS

Dataset is acquired from PhysioBank ATM offered by PhysioNet. Utilized databases are T-wave alternans challenge database (TD), QT database (QTD), and MIT-BIH ST change database (STD). Another dataset is contributed by the permission from Institutional Review Board (IRB) at Yonsei University Gangnam Severance Hospital, Seoul, Korea. The dataset, contributed by the IRB, is selected for the database with QT prolongation moment (QTPM). In Table 1, the heart beat-order showing the maximum and minimum values of QT interval is identified among heart beating cycles for each dataset. Datasets TD51 and TD52 contain 12-lead EKG data. The third or twelfth beat of dataset TD51 showed longest QT interval with highest amount of amplitude standard deviation, and the sixth or seventh beat of dataset TD51 showed shortest QT interval. The seventh or eighth beat of dataset TD52 showed longest QT interval with highest amount of amplitude standard deviation, and the thirteenth or fourteenth beat of dataset TD52 showed shortest QT interval. Dataset QTD and STD also represented that heart beat with long QT interval has a tendency to be high amplitude standard deviation.

QT prolongation was observed in dataset QTPM as long as 904 milliseconds. As each given sampled dataset has uniform sampling frequency, QT interval with the number of data between the Q point and the end point of T-wave is substituted to the time required from depolarization and repolarization of the left ventricle. The QT prolongation was consistently observed throughout whole data in dataset QTPM, and relative QT dispersion of dataset QTPM became lower. However, dataset including sudden onset of QT prolongation causes significant increase in relative QT dispersion.

When heart beats with the maximum amplitude standard deviation have shorter QT interval than the maximum QT interval within same dataset, they are marked with asterisk mark. The heart beats with the maximum QT interval still tend to have high amplitude standard deviation, even when amplitude standard deviation is smaller than the heart beat with asterisk mark.

Dataset QTPM is shown in Figure 2 with blue dots that represent data elements of each QT interval. The x-axis is the number of data, while y-axis is normalized amplitude. In dataset QTPM, the fourth QT interval showed the longest interval, and every beat showed QT prolongation, longer than 685 milliseconds.

DISCUSSION AND CONCLUSION

The QT interval is equivalent to the duration of depolarization and repolarization actions of the left ventricle. As depolarization occurs for the left ventricle, the collected blood starts to flow through every blood vessel. Left ventricle polarization generates QRS complex that consists of data with high amplitude as shown in general heart beat electric signal waveform. Repolarization of the left ventricle releases the contracted muscle of the left ventricle, and generates T-wave.

Heart beats in long QT interval include more waveforms in the QT interval. The heart beat waveform in long QT interval represents high standard deviation of amplitude values that result in the blood flow variation of depolarization and repolarization. The blood flow variation of depolarization and repolarization affects extra complementary action of the left ventricle with its muscle activation variation. The risk of arrhythmia symptom during ischemic blood flow is being increased when the amount of QT interval variation, represented as relative QT dispersion, becomes high. The proposed T-wave variation characteristics evaluation algorithm can be further developed for abnormal channel decision of 12-lead EKG.

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