Survey on electrocardiography signal analysis and diabetes mellitus: unraveling the complexities and complications

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Article Info

Article history:

Received Aug 21, 2023
Revised Nov 22, 2023
Accepted Dec 13, 2023

Keywords:

Correlation
Diabetes mellitus
Electrocardiography
QRS complexes
Signal processing

ABSTRACT

Electrocardiography (ECG) is crucial in the medical field to assess cardiovascular diseases. ECG signal generates information, i.e., QRS complexes that imply the cardiac health of the human body. It is depicted in the form of a graph with voltage versus time interval. A distorted, inverted, lagged, small waveform implies an abnormality in a cardiac system. This study highlights the generation of an ECG signal, QRS complexes undertoned towards different diseases, event detection, and signal processing methods. It has become crucial to highlight the possibilities and advances that can be derived from an ECG signal. Throughout this study, an instance of diabetes mellitus (DM) is considered for creating concrete awareness and understanding of an ECG signal in DM. This study focuses on finding the correlation between ECG and DM. Detection of DM from ECG signal is also studied. The findings of this survey paper conclude that the correlation between DM individuals with cardiovascular complications has autonomic neuropathy, which may lead to myocardial infarction. It is also found that the QRS complex and its abnormalities are not specific to complications in DM. However, non-invasive detection of diabetes through ECG signals demonstrates future research potential.

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1. INTRODUCTION

ECG represents the electrical activity of the cardiac signals. They are the source of information on cardiac activity. They contain diagnostic information related to various diseases related to the heart. ECG signal is represented in the canonical pattern. When an ECG signal gets electrical stimulation, the heart muscles contract. The contraction has a mechanical effect on the atria and ventricles. This gives rise to depolarization waves of the bioelectric signals by also affecting the nearby cells in the heart. Due to the electric potential, depolarization occurs, and then the muscle cell relaxes back where repolarization happens. The pre and post-state of depolarization and repolarization are represented in a waveform, as depicted in Figure 1 [1]. The waveform obtained through ECG is known as "P, Q, R, S, T," as depicted in Figure 2. From a clinically taken ECG waveform, segments can be extracted. The P, Q, R, S, and T waveforms reveal important properties and the nature of the waveform. The measurement taken can be positive or negative depending on the nature of the waveform. RR wave is the distance/interval between two R waves successively. The R wave is the peak in a QRS waveform. HR is the heart rate that can be inferred from the waveform. R-H depicts the height of the R wave (millivolts). P-H depicts the height of the P wave (millivolts). QRS is the time interval between Q, R, and S waves. PRQ is the interval between the P wave and the R wave's peak. QT is the interval between Q and T waveform in milliseconds. QTC is the corrected interval between the Q and T waveforms. ST is the interval between the S wave to the beginning of T wave(millivolts) [2].

The comparison of current state-of-the-art on ECG survey with the proposed work is presented in Table 1. The medical and engineering branches are associated with ECG analysis, and its interpretation. Previous survey papers on ECG and DM are completely aligned towards respective branches of the study. In a study, the biology of ECG and the detection of DM is elaborated in [3]. In a similar work, the biological science of ECG and the signal processing of ECG is detailed in [4], [5]. The discussion on ECG is restricted to signal processing in [6], [7]. The biology of ECG and the correlation of ECG and DM with DM detection are thoroughly explored in [4]. Signal processing methods are elaborated in [2], [4], [8]. Our study aims to provide insights to a researcher or any other curious minds to understand every aspect of ECG by integrating ECG, its biological significance, signal processing methods and correlation of ECG and DM which have not been focused on the previous studies.

The contribution of the current work is as follows: i) The proposed survey introduces the integration of ECG, its signal processing methods, and the correlation of ECG and DM; ii) Effect of ECG on DM is discussed thoroughly and iii) The correlation between ECG and DM is extensively investigated in our study. It was inferred that the complications are not specific to DM.

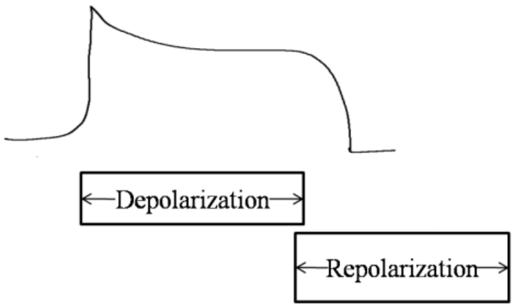

Figure 1. Depolarization and repolarization

Table 1. Comparison of current state-of-art with our work

Reference	ECG	Signal processing method	Correlation of ECG and DM
Goutham *et al.* [3]	✓	×	×
Kittnar *et al.* [4]	✓	×	✓
Dewangan and Shukla *et al.* [5]	×	✓	×
Lamba and Rawal *et al.* [6]	×	✓	×
Vincent and Sreekumar *et al.* [7]	✓	✓	×
Satija *et al.* [8]	×	✓	×
Berkaya *et al.* [9]	×	✓	×
Thorén *et al.* [10]	✓	✓	×
Our Work	✓	✓	✓

This review paper is organized as follows: Section 2 provides information on ECG-based general disease analysis. Section 3 describes the effect of ECG on DM. Section 4 provides the correlation analysis of ECG with DM and their signal processing methods. The discussion is further followed by future scope and challenges in section 5.

2. ECG-BASED GENERAL DISEASE ANALYSIS

The position of cardiac system can be clearly emphasized with ECG graphs. In the case of cardiac arrests, ECG is a powerful tool for predicting the next 30 days of survival in case of in-hospital cardiac arrest [10]. Monitoring ECG is an essential practice in cardiac research [11]. Insight on ECG will be further discussed.

2.1. The significance of electrocardiography

Electrocardiography (ECG) is measured through leads. The standard method of recording ECG is by 12-lead electrodes. It records the cardiac activity along with the membrane potential non-invasively. The 12-lead electrodes are placed at twelve different locations for recording the cardiac activity as shown in

Figure 2. Among the 12-leads, three are the limb leads placed across the limbs with lead number 9, 10, and 12, three are the unipolar limb/ augmented leads with lead number 7, 8, and 11 for modulating the augment vector right arm (aVR), augmented vector left arm (aVL), and augmented vector leg (aVF). The remaining six are the precordial chest leads with lead number 1 to 6 placed on the chest [10]. These placements record the electrical activity from different parts of our body.

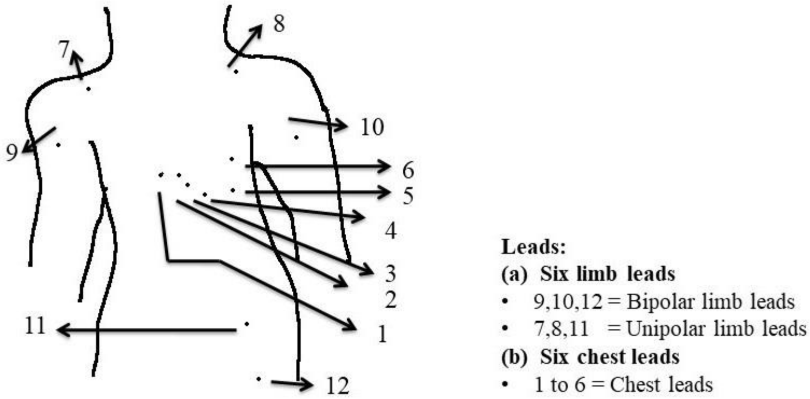

Figure 2. Tracing ECG waveform

The ECG monitor displays the tracing of the waveform. Printout of the waveform with or without a grid is taken for analysis and reference. A standard ECG waveform is voltage, and the direction of the waveform is depicted at the vertical axis from the baseline. The time and sequence of events are depicted on the horizontal axis. Larger and smaller squares form a standard ECG recording paper. Each square represents a 0.04-second interval. Five squares constitute a large square that represents a 0.20 sec interval. Therefore, ECG is known as a moving graph at 0.04 and 0.20 sec [12]. The recording waveform is traced on the paper for further analysis and reference. The analysis of the graph and waveform, the importance of horizontal and vertical axis, and their implication on different diseases will be discussed in further sections.

2.2. Event detection and analysis of ECG waveform

When an electric current is passed through the ECG electrodes, an electrical response is generated in the cardiac cells. The cardiac activity is recorded in the form of a waveform that contains diagnostic information [1], [4]. The waveform is represented as "P, Q, R, S, T," which is depicted in Figure 3. During a disturbance in the cardiac cycle, the propagation of the wave changes. The abnormalities in the heart are inferred from missed events, shortening and lengthening of the waveform, and changes in amplitudes [1], [4].

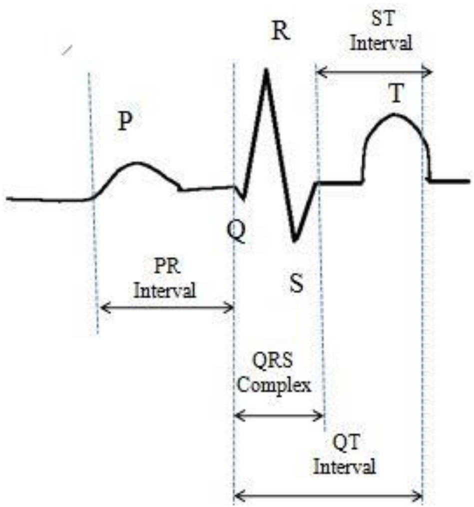

Figure 3. PQRST waveform

3. EFFECT OF ECG IN DIABETES MELLITUS

The ECG of a normal individual differs from that of an individual with cardiac and other physiological system diseases. Heart rate variability (HRV) or distortions in P, Q, R, S, and T waveforms can detect heart conditions or abnormalities [2], [13]. Diabetes mellitus (DM) is a metabolic disorder that is a threat to the human race. WHO estimates that the number of deaths due to DM has increased from 1.5 million in 2019, and it is said to increase further [2]. Poor cardiovascular prognosis is associated with DM. Due to sensitive neuropathy in DM individuals, postural hypotension, exercise intolerance, intraoperative cardiovascular liability, asymptomatic ischemia, myocardial infarction, atherosclerotic cardiovascular, peripheral arterial, cerebrovascular disease, abnormalities of lipoprotein metabolism are commonly found [2], [14]. It can be inferred that the heart rate variability (HRV) and its affect on the ECG (fluctuations and distortions) can provide more information on the state of a diabetic individual and the prediction of other cardiovascular diseases.

a. Impact of P wave: Absence of P wave with irregular and rapid ventricular rate leads to atrial fibrillation [15] and atrial depolarization [16].
b. Impact of PR interval: AV blocks are detected when P-R interval increases beat to beat until it reaches QRS and drops at T [17].
c. R wave: Heart rate variation (HRV) is the variation in the heart rate [2], [14], [18]. Normal individuals with high resting rate and low heart rate viability have an increased risk of DM in the future [19].
d. Impact of QRS interval: QRS complex is reduced when an individual has DM1 with cardiac autonomic neuropathy (CAN) [20]. Atrial flutter is caused by a large re-entrant pathway inside the atrium, which is depicted as a fluttered QRS complex in the waveform [15]. Ventricular conduction defects are due to blockage of left and right bundle branch blocks in the heart. It is depicted when QRS$>$0.12 s for a majority of the beats and, R peak duration$>$0.06 s and S duration$>$R duration [21].
e. Impact of QT and QTc interval: In gestational diabetes mellitus and CAN (with DM) individuals, non-significant lengthening of QT and QTc is found [16], [21], causing tachycardia. Prolonged QT interval causes diabetic autonomic neuropathy, which is the cause of silent death/myocardial infarction and cerebrovascular mortality [14], [22].
f. Impact of QRS and QT interval: For a normal person, during Tachycardia (shortening of QRS complex) there is a shortening of QRS [13]. Though no change in axis and amplitude of QRS complex was found between DM and normal individuals, QRS duration was higher in DM individuals [16].
g. Impact of and ST interval: ST depression causes mortality in DM-Type II patients [16], [23].
h. Impact of QS interval: Body surface map reveals decreased R wave amplitude and increased Q and S waves in DM1 individuals [13]. Q-Qs into interval is found more in individuals with DM [24].
i. Impact of T interval: Ventricular repolarization is depicted by T wave [16]. Flattening of the T wave is found during repolarization in DM1 individuals [16]. T wave abnormality with abnormal ST depression, left ventricular hypertrophy, and disorder in repolarization are the signs of myocardial infarction. T wave inversion is predominant in DM individuals [24].

4. CORRELATION ANALYSIS OF ECG WITH DIABETES MELLITUS AND SIGNAL PROCESSING

The abnormalities and disturbances in ECG indicate different diseases. This section will focus on finding the correlation of ECG with DM. Signal processing methods that are applied in detecting ECG and prediction of DM are discussed in this section. Research related to ECG signal processing method and the prevalence of ECG abnormalities in diabetic patients is illustrated in Table 2. From the ECG waveform, QT, ST, and PD (P wave dispersion) are obtained by implementing a high pass filter, mutual entropy, and correlation coefficient [25]-[36]. Central information dimension and LabVIEW are implemented in [26] to obtain RR wave. Few studies have implemented LabVIEW and MATLAB for determining QT [28]. HRV from ECG signal is received by the Pan Tomkins method of signal processing and neuropathic conditions [29]. QR-TT's prolongation is evident in T2DM patients, leading to ventricular abnormalities and in predicting neuropathy [27]. On the other hand, prolonged QT is observed due to low blood glucose and a fall in the blood glucose level as well [28]. The prevalence of cardiovascular risk disorder features in DM individuals is obtained using linear regression [30].

Various cardiac conditions are studied from the diabetic database in [31] with the obtained QRS complex. In this study, it is unclear whether the presence of abnormal cardiac conditions may indicate DM whereas in [32], morphological features of ECG detect premature ventricular abnormality and ischemic disease. Tangent approach is implemented to determine the impact of QT prolongation in DM patients [17].

Wavelet transform and central information dimension are implemented to obtain QT [26], [32]. The signal processing method applied is Minnesota classification for determining Q, R, and T [34]. DM detection from QRS complexes is explored with curve tracing in [27], [33]. QT and ST distortion from ECG complex are extracted to detect DM [27], [34].

Table 2. Signal processing methods applied in detecting ECG complexes from DM database

Reference	Purpose	Signal processing method	Inference
Gonçalves and Coelho [25]	ECG patterns for detecting DM.	Linear approximation, Kalman filter, dynamic time warping.	• A device to estimate diabetes was designed.
Ma *et al.* [26]	Detecting diabetes triggering features.	Central information dimension.	• Central dimension method has shown better results (p<0.001).
Bharadwaj and Paul [27]	Detection of DM in unhealthy patients.	P, QRS, T, QT, RR, QRS, ST	• Changes in cardiac rhythm is found in DM patients. • Abnormal left ventricle of the heart in T2DM patients.
Imam *et al.* [28]	Analyzing cardiac autonomic neuropathy in ECG using systolic and diastolic intervals	LabVIEW software and semi-automated template matching method.	• TQ-RR-based measured blood glucose levels by differentiating all groups. • QT-TQ showed differentiation in -CAN and DCAN groups.
Yildirim *et al.* [29]	Automatic detection of diabetic subject.	HRV	• Accuracy=97.62% • Sensitivity=100%
Harms *et al.* [30]	Detecting ECG abnormalities in DM-Type II patients.	Minnesota classification	• Resting ECG abnormalities were common in DM -Type II patients, irrespective of the history of CVD. • Sensitivity=99.75%Specificity=99.83%
Sidek *et al.* [31]	Detecting abnormal cardiac conditions from the Diabetes database.	Biometric technique.	k-NN with • 6 QRS =0.98. • 8 QRS samples=99.3 • 10 QRS samples=99.8.
Maršánová *et al.* [32]	Ventricular premature & ischemic heartbeat.	Wavelet transforms.	• Max accuracy with k-NN =98.6%.
Porumb *et al.* [33]	To detect nocturnal hypoglycemia.	R peak, QRS	• Glucose levels, heartbeat, and activity is more intense in DM individuals.
Gupta *et al.* [34]	Detecting asymptomatic T2DM.	QT, ST-T	• ECG changes are present. • Non-specific ST-T changes. • Left ventricular hypertrophy, Left atrial enlargement.

The drawback of the traditional implementation of detecting the waveform is the artifacts' interferences in real-time. The methods applied may take longer for computation and are sensitive to unknown noises. Extraction of peaks and troughs from an ECG waveform must be done very fast in order to save computational time. This can be achieved through ML algorithms. The advantage of ML algorithm is that two or more algorithms can be combined together to achieve more accuracy [35].

From the above literature review, it is evident that the detection of DM from ECG signals is possible. The non-invasive method is feasible by identifying the ECG parameters that show significant change in DM and non-DM patients. However, few studies have contradicted this idea. The abnormalities present in ECG for DM patients are also present in other diseases. There are many diseases and drugs, i.e., antidepressants and antipsychotics that influence the HRV and other health parameters [36]. As the absence of P wave creates atrial fibrillation in DM patients, P wave dispersion is present in both diabetic and non-diabetic individuals [36]. Variation of the R wave in HRV has an increased complication of DM in the future [19]. The duration of QRS is found to be higher in DM individuals [24]. The presence of an abnormality is not specific to DM individuals, whereas this holds a research potential.

5. CONCLUSION

ECG is a hub of diagnostic information that implies the cardiac health of an individual. This survey aimed to highlight ECG, its abnormalities, and its correlation with DM. Different studies related to ECG and its abnormalities have highlighted the possible cardiovascular complications in DM individuals. It can be inferred from the proposed survey paper that though ECG helps imply cardiac diseases in DM individuals, there is still no evidence that specific QRS, QT, RR distortions can only be seen in DM individuals. This does not mean that there is no correlation. The study of correlating ECG and DM is a field of an immense potential. A new multidisciplinary field focusing on creating a reliable diagnostic system through ECG is thoroughly explored. General disease analysis on ECG is surveyed in this paper. The prevalence of ECG in DM individuals is thoroughly explored. Different signal processing methods and correlation analysis is investigated. This nuanced survey will guide the new researchers in this field. ECG information is useful when implemented in different scenarios through the amalgamation of ML/DL, and signal processing methods. This will drive towards advanced technology and a boon for the human race. There has to be a lot of work done to improve the efficiency in detecting diabetes in the following areas of obtaining better sensitivity and accuracy for DM predictions and other features such as cholesterol, insulin resistance, and obesity. Implementing ML/DL for the prediction and detection of DM with the generation of alerts through the mobile with any patient-doctor interaction platform will be highly useful in health care.

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